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Final Report to the Bureau of Land Management on Development of Large Cetacean Tagging and Tracking in OCS Lease Areas

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by

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INTRODUCTION

The Bureau of Land Management (BLM) is responsible under various statutes for the orderly development of the resources of the Outer Continental Shelf (OCS) as well as protection of the marine and coastal environments encompassing the OCS lands. The Marine Mammal Protection Act of 1972 and the Endangered Species Act of 1973, as amended in 1978, establish a national policy that marine mammal populations, and especially endangered marine mammal populations, should be protected and encouraged to develop to the greatest extent possible. In order to predict and assess the possible first and second order effect of oil and gas development on marine mammals and to determine jeopardy to the continued existence of endangered marine mammals species, the Outer Continental Shelf Program of BLM has undertaken studies to gather data on these animals and the OCS ecosystems. Because whales spend only about five to fifteen percent of their time at the surface they are difficult to study and to do so requires innovative techniques and technologies. With the recent development of improved attachment techniques and advanced transmitter technology, radio tagging free-ranging large cetaceans is becoming a viable method for collecting movement, activity pattern, habitat use pattern, and behavior data from these elusive animals.

There are essentially three types of research possible utilizing radio tracking technology: 1) short term behavior, activity and habitat utilization studies, 2) longer term migration and distribution studies, and 3) telemetry studies yielding information about the physiological state of the whales and about their environment. Standard radio frequency (RF) tracking techniques can be used to gather data on behavior (including effects), activity patterns, and telemetry on a short term and rather local basis. However, to gather longer term information on habitat utilization, distribution, migration, and long term physiological and environmental parameters, satellite-linked technology is essential, since logistical and cost factors preclude any other method of signal acquisition.

The purpose of this contract was to provide BLM with an overview of radio tracking potential for large cetacean research in the OCS, to test the feasibility of radio tracking bowhead whales, and to initiate the development of a satellite-linked transmitter (SLT) for the remote acquisition of whale location, movement, and distribution data. The specific objectives of the program were to:

- synthesize existing information on tagging and tracking systems addressing the advantages and disadvantages of individual tags and tracking systems for large cetaceans and identify the technology gaps necessary to advance the state of the art to a safe and reliable level
- conduct a field experiment to determine the feasibility of radio tagging and tracking bowhead whales in the Beaufort Sea, ultimately via satellite, and
- design, fabricate and test a SLT for attachment to large cetaceans.

TAGGING AND TRACKING SYNTHESIS

Although man has studied the lives of the other animals with which he shares his world since the earliest times, not until the nineteenth century were systematic marking programs initiated to aid those studies. Prior to that time careful field studies had provided a wealth of information concerning some phases of wildlife natural history but scientists recognized the need for more information about territory and home range, social structure, population structure, and migration routes. Thus tags and marks that had been used primarily to establish ownership or to carry messages were modified, improved, and used in conjunction with newly evolving analytical techniques for the rigorous study of the ecology and behavior of animals.

The earliest marking studies were carried out on birds and fish. Fisher and Peterson (1964) ascribe the first bird marking to Quintus Fabius Pictor. "Sometime between 218 and 201 B.C., when the second Punic War was on, this Roman Officer was sent a swallow taken from her nestlings by a besieged garrison. He tied a thread to. its leg with knots to indicate the date of his relief attack and let the bird fly back." By the eighteenth century a wide variety of birds including falcons, herons, swans, and ducks were marked with various types of name plates and metal collars, and during the late nineteenth century a Dane by the name of Mortensen developed the aluminum leg band which was the foundation for all subsequent bird banding. By the nineteenth century various fish species were also being marked. Early salmonid studies using ribbon, brass wire, fin cutting and numbered tags demonstrated that these species returned to their native rivers to spawn after spending several years at sea.

for years.

The first mammals to be systematically marked were the northern fur seals of the Pribilof Islands in the mid-nineteenth century. The seals were marked by removal of the ears to determine their dispersal, movements, and homing specificity to the rookery of their birth. Later, fur seals and other pinnipeds were marked by a variety of methods including branding, dyeing, painting, hair removal, and many different tag types (Scheffer, 1950; Hobbs and Russell, 1979). By the 1930's the marking of small mammals had become a routine method of study, but the capture and application of tags and marks to large mammals still proved difficult. It was not until the development of safe drug immobilization techniques in the 1960's that other large mammal marking became a significant research technique. A thorough review of the history and use of animal marking and tagging is found in Stonehouse (1978).

Although a large number of marking and tagging techniques have been developed and used for the study of animals, most cannot be used successfully on cetaceans because of their physical characteristics, habitat and general invisibility above the water surface. Cetaceans have no hair and their epidermal tissue sloughs very rapidly so it is impossible to clip them or mark them with paints or dyes. Their body shape, fusiform and highly adapted for aquatic living, makes it difficult and potentially dangerous to the animal to attach identifying objects on the external body surface. Because cetaceans are widely and relatively sparsely distributed, they are difficult and expensive to capture and are essentially impossible to anesthetize in the field for surgical practices. The cetaceans that BLM is concerned with live entirely in the oceanic environment and therefore pose special problems concerning longevity and decomposition of materials for tags and marks. The problems of capture and handling obviously become more difficult as the size of the cetacean increases.

Despite these overwhelming obstacles, the marking and tagging of cetaceans has long been recognized as the only way to gain insight into their otherwise unknowable life history. There are three generalized methods of recognizing individual whales, dolphins, and porpoises: 1) natural markings, 2) static tags, and 3) radio and sonic tags. Each method will be discussed and evaluated especially in light of their applicability to the large cetaceans.

Natural markings

Since early times people have been able to identify individual animals by their unique markings. Early whalers, for example, knew of distinctively marked or anomalously colored whales like the famous all-white bull sperm whale after which the novel Moby Dick was patterned. Researchers today use natural markings and unusual appearances to identify individuals and monitor their behavior and movement. Pictorial catalogues, for example, have been compiled of gray whale markings (Swartz and Jones, 1980; Darling, 1977), humpback whale fluke patterns (Kraus and Katona, 1977, 1979; Lawton et al., In press), and killer whale dorsal fin shapes and coloration patterns (Balcomb 1978, 1980). One of the major questions regarding this method of identification is the reliability and longevity of recognizable markings or deformities. Available results indicate that identification is possible in most cases over a period of at least a few years and thus valuable data can be gathered about site tenacity over seasons as well as short term migration and home range, social interactions, activity patterns and habitat use. The main drawbacks of this system are the requisite high labor intensity for data acquisition and the small area of possible coverage. Thus, the limited availability of large, cheap labor pools and local concentrations of cetaceans with a large portion of identifiable individuals generally preclude such studies.

Static Tags

Whalers before the turn of the 20th century occasionally found old harpoons imbedded in the tissues of freshly killed whales, evidence of a previous unsuccessful hunt. From reports of these harpoons, cytologists conceived of marking whales with labeled harpoons as a means of gathering information on migrations, size of stocks, and effects of exploitation by the whaling industry. Following a successful experimental tagging cruise in 1932/33, an extensive tagging program was underaken by the British Discovery Investigations using 23 cm-long metal tubes fitted with a ballistic head. These marks, which became known as Discovery tags, were fired from a 12-gauge shotgun into the flesh of the whale. Later, marks were also made for smaller whales and were shot from a 410–gauge shotgun. Each tag was labeled with a serial number and an address for return. A reward was offered for receipt of the tag along with vital information concerning the animal and its taking. Although the Discovery Committee discontinued its involvement in this marking effort in 1939, Discovery-type marking by agencies in many whaling countries continues today (for review see Brown, 1978).

It was not until the 1960's, when interest in cetacean studies greatly increased, that investigators began to experiment with methods of tagging and marking which did not depend for their success on killing of the animal. As a consequence a variety of externally visible tags and marks were developed to give the investigator a temporary or permanent record of the identity of individual cetaceans.

Because some porpoises and dolphins often ride the bow pressure wave of boats and ships, they are relatively easily captured or tagged from a moving vessel. In recent years, at least three types of spaghetti streamers and five types of dorsal fin tags or marks have been placed on small cetaceans.

The spaghetti streamers initially tested on cetaceans by Nishiwaki et al. (1966) and Sergeant and Brodie (1969) are generally placed just forward of the dorsal fin, a bit to either side of the midline of the back. These tags can be attached to free-ranging animals with a pole applicator (Evans et al., 1972) or crossbow (Kasuya and Oguro, 1972) and do not require capture. The tag consists of a stainless steel barb which penetrates through the blubber just into the muscle; a stainless steel or monofilament leader which is attached to the barb and passes out through the skin; and an attached streamer which may be a color-coded extension of the leader or a wide, flat strip of tough plasticized material which trails along the animal's body. Spaghetti tags are numbered and often labeled with an address for return. Because of their small size, the labels cannot be seen on a free-ranging dolphin, even at close range, and specific information can only be obtained when a tag is examined closely on a captured animal or extracted from an animal, usually postmortem. Color coding, however, can often be recognized from a distance and may provide critical information concerning the date and location of tag placement and subsequent movement of the animal. Despite early success with spaghetti tags (Perrin et al., 1979), extensive testing led NMFS to discontinue their use for studies in the eastern tropical Pacific (Jennings, pers. commun.) because tag entry wounds did not heal which caused high tag loss rates.

When investigators need more specific and longer-term information about the porpoises and dolphins being studied, they may be required to capture the animal and apply more readily visible tags and marks with individual coding. The dorsal fin is generally chosen as the site for tag/mark placement, since it is the most prominent and easily observed portion of a surfacing cetacean and is thought to be more durable than other potential sites (Evans et al., 1972). Small triangular wedges clipped out of the tough connective tissue on the trailing edge of the dorsal fin have facilitated identification of individual cetaceans in some studies. Alternatively, button or disc tags are placed near the center of the dorsal fin and are held on both surfaces by a central bolt which passes through the fin (Evans et al., 1972) and rectangular visual tags are held in place with two bolts (Irvine and Wells, 1972). The smaller Jumbo roto tags, a type of cattle ear tag, pivot on a single stud which passes through the trailing edge of the dorsal fin (Norris and Pryor, 1970). Finally, flag tags, which also pivot on their leading edge, have been tested in captivity (Evans et al., 1979), but these larger tags have not, at this writing, been used in the field. The tags mentioned above have characteristic symbols or alphanumeric designations that allow individual identification at varying ranges depending on their size.

Freeze brands, symbols and alphanumeric designations applied to skin tissue with irons which have been cooled in liquid nitrogen or dry ice and alcohol, have proven effective as permanent marks which are highly visible at moderate ranges (Cornell et al., 1979; Irvine and Wells, 1972). These marks have been placed on the back of small cetaceans (for aerial observers) or on the dorsal fin (for surface observers) causing no apparent discomfort to the animal. Irvine et al. (1977) report a longevity of at least four years on a bottlenose dolphin.

During the mid 1970's a great deal of research went into tag and mark development for population studies of the small cetaceans taken incidentally to the tuna fishery in the eastern tropical Pacific. Flow tank and live animal tests provided extensive information on materials and designs including: disc tags, rototags, tail stock bands and streamers, spaghetti streamers, button tags, surveyor's tape streamers, dorsal fin clips, dorsal body clips, fin clip saddles, tetracycline teeth deposit marking, tatooing, and freeze branding (Anonymous, 1978; Evans et al, 1979). Despite these exhaustive studies, no optimum static tag has been successfully field tested.

The methods described above have been utilized on a variety of smaller cetaceans. However, due to the obvious difficulties of handling the larger whales, only remote application of tags and marks is practicable. To date, only spaghetti tags (Norris et al. , 1976) streamer tags (Mitchell and Kozicki, 1975; Rice et al., 1979), paint and freeze branding have been tested in external marking of large whales. Because the life expectancy of streamer tags is so short and the probability of refighting so poor, only sporadic effort has gone into adapting these methods to whales and the results of such programs have been equivocal (Brown, 1978). Paint marking, tested on California gray whale barnacles (Hobbs, unpublished) after unsuccessful tests on the skin of porpoise by Watkins and Schevill (1976), failed to leave a distinguishing mark after the first submergence, and the freeze brand applied to the released captive gray whale, Gigi, was not resighted after early contact was lost (Evans, 1974).

Sonic Tags

Leatherwood and Evans (1979) summarized the developmental work in applying acoustic tracking devices to cetaceans as follows:

"Early attempts employed acoustic tracking devices developed for the study of fishes. Schultz and Pyle (1965) attempted to attach acoustic transmitters mounted on shallow harpoon heads to California gray whales (*Eschrichtius robustus*). Payne (1967, Rockefeller University, personal communication) similarly attempted to track humpback 'whales (*Megaptera novaeangliae*) using acoustic devices. In 1967-1968 one of us (Evans) tested the potential use of sonic transmitters attached by a suction cup to a captive *Tursiops truncatus* (unpublished data). None of these attempts met with any success. The primary problems identified were that (1) ranges obtainable were unacceptably short; (2) transducers, both transmitting and receiving, were inadequate; and, importantly for future approaches, (3) the projectors used frequencies that fell within the hearing ranges (e.g., see Johnson, 1966) of these highly acoustic animals. There were significant problems in all these cases with successful attachment and operation of the transmitters. But even if these technical problems had been overcome, it is highly questionable whether data obtained from these systems could have represented "normal" behavioral patterns for the tagged animals."

Even Kanwisher (1978) who reports the successful telemetering of physiological_ data from unrestrained porpoise muses that "The possibility also arises that, upon realizing they are listening to their own heartbeat, the animals will be fascinated and vary the rate for their own amusement." Watkins (1978) decided early in his cetacean tracking development program not to use sonic devices on these acoustically sensitive animals. Irvine (Pers. commun.) found while using sonic pingers to study the movements of manatees that ranges were so short (about 400m) that if a tagged animal were ever lost they were highly unlikely to relocate it, even in the confines of the St. Johns River. Irvine also found sonic signals to be sharply confined within a thermal plume and reduced to 30 m reception within the plume. These reasons combined with the highly unpredictable sound paths of the oceans, suggest that it is unlikely that any future development in acoustic tracking would produce a system capable of tracking free-ranging cetaceans, except for short distances and time spans.

Radio Tags

Since cetaceans spend 85% to 95% of their life underwater, move during the night as well as the day, and often vanish from the watchful eye of an observer, even though they may be clearly marked or tagged, the development of tracking devices for whales and porpoises has greatly aided investigators in studying the life history of these animals. For a comprehensive review of tracking systems see Michelson et al (1978) and of radio telemetry see MacKay (1970). In 1961, Shevill and Watkins (1966) began development of a radio transmitter for right whales, *Eubalaena glacialis*, based on the design of the early discovery tag marks. Although the investigators were unsuccessful in tracking whales with these early transmitters, they did serve to show the feasibility of the attachment of radio transmitters to large cetaceans. During this same time period, other investigators (see Evans and Sutherland, 1963) were also considering the use of telemetry in the study of marine animals. Between 1967 and 1971, Evans (1971), in conjunction with Ocean Applied Research (OAR), developed a small radio beacon that could be attached to porpoises utilizing existant high frequency (HF), citizen band technology. Because of their short surface times, it was immediately evident that automatic direction finding (ADF) capabilities were essential to the successful tracking of free-ranging cetaceans, and so an ADF was developed by OAR for use in the HF band range (Martin et al., 1971).

There followed two basic methods of attaching radio transmitters to large cetaceans: animals were captured and physically restrained in some manner so that a radio transmitter could be attached or radios were attached by various remote methods. In the former case, Norris attached OAR radio transmitters to gray whale calves with flexible elastic harnesses in Baja California and successfully tracked them for up to four days (Norris and Gentry, 1974; Norris et al., 1977); Evans (1974) attached a radio transmitter to a yearling gray whale with sutures in southern California and tracked that animal sporadically along the California coast; and Erickson (1978) attached a VHF radio transmitter to the dorsal fin of killer whales by using stainless steel pins and tracked those animals intermittently in Puget Sound, Washington for five months. Watkins and Schevill continued their remotely implantable whale beacon testing and development program in conjunction with OAR through the 1970's (for a review of this development program, see Schevill and Watkins, 1966; Watkins and Schevill, 1977; and Watkins et al., 1980). Throughout the developmental stage of this radio tag, various design changes have been made, but the concept of a stainless steel shaft implanted within the body of the whale with only the antenna exposed has remained constant. These radio transmitters have been implanted in a number of species of whales and have evolved with each testing. Ray et al. (1978) tagged and successfully tracked fin whales in the St. Lawrence River; Tillman and Johnson (1977) tagged and tracked humpback whales in southeast Alaska in 1976 and again in 1977 (Anonymous, 1977); Watkins et al. (1978; in press) radio-tagged and tracked finback and humpback whales in Prince Willilam Sound, Alaska; Watkins et al. (1979) tagged, but were unable to track, Bryde's whales in Venezuela and Watkins (1981) successfully tagged and tracked fin whales near Iceland.

Starting in 1978, the Bureau of Land Management contracted for the development of alternate systems for the remote attachment of radio transmitters to free-ranging large cetaceans with the expectation of greater longevity than the 17 days demonstrated at that time (Watkins et al., 1978). Bruce Mate, working with Telonics, Inc. , of Mesa, Arizona designed and tested an umbrella stake attachment which penetrates the skin about 2 1/4 inches and flares on entry. These VHF transmitters were used to successfully track gray whales (Mate, 1979). Mate (1980) also developed a barnacle radio tag implantable by bow or gun which was also successfully tested on gray whales. Follmann (1980) concurrently developed and tested a VHF radio tag with an attachment head that toggled approximately 2 inches under the skin and a transmitter and antenna that laid flat along the external surface of the animal. He was, however, unsuccessful in tracking these animals.

At the same time that investigators were first successfully radio tracking small cetaceans, Craighead et al., (1972) were testing a satellite-linked tracking device for free-ranging animals on elk. Although these first tests were hampered by the extreme size and weight of the transmitters and were generally thought to be unsuccessful, they led to a great deal of interest in the possibility of developing smaller, viable transmitters suitable for studies on animals as wide-ranging in size and habitat as birds and whales. A series of meetings during the late 1960's and early 1970's defined at great length the needs for satellite tracking, the technological gaps at that time, and the priorities for development (Galler et al., 1972; Anonymous, 1974). However, it was not until the Fish and Wildlife Service (Kolz et al., 1978) successfully satellite tracked a polar bear for over one year and S300 km that interest in satellite tracking was revived. Based on that success, NMFS embarked upon a satellite-linked transmitter development (Jennings and Gandy, 1980) for attachment to small cetaceans in the eastern tropical Pacific. This program has met with a great number of problems, both electronic and biological, but success is anticipated within FY81. Both the polar bear and and the porpoise transmitters remain too large for general application to marine mammals so BLM has awarded this contract for the next stage in the miniaturization and development of a SLT.

Evaluation and discussion

There are currently three basic transmitting and receiving systems and four different types of attachment for large cetaceans. Woodbridge

(1978) discussed another potential animal tracking system using extra low frequencies (ELF), but its use on cetaceans must be rejected due to excessive power requirements, large size, and possible interference with hearing and communication. Each system has its benefits and shortcomings and will be discussed in the following paragraphs.

High frequency (HF) systems (27-30MHz) - The greatest advantage of using high frequency systems for radio tracking at sea is the relatively great theoretical tracking distances attainable from shipboard because HF radio waves follow the curvature of the earth. Another advantage is the availability of a relatively efficient ADF, an essential component of any operational radio tracking program. The major drawback to working at this frequency is the inefficiency of antennas which limits tracking range and, more importantly, necessitates larger radio tags because of the battery demands required to achieve adequate radiated power. Additionally, because frequency scanners or other means of individual identification are not available at HF, multiple receivers are required to simultaneously track more than one transmitter.

The WHOI/OAR radio tag is currently the only attachment/deployment system available in the HF band. The maximum longevity of the latest iteration of this tag is untested but there was no indication of rejection after nine days in the Iceland tests (Watkins, 1981). The major advantage of the WHOI/OAR tag is the 30 m deployment range which makes it potentially useable on any species of large cetacean. Retuning of the antenna has solved some of the early problems with reduced range due to poor antenna-orientation. Because of the differential movement of tissue layers through which the tags pass, the problems of healing and continuous irritation to the animals persist. Considerable practice and marksmanship skill are essential when using this tag system.

Very high frequency (VHF) systems (148-164 MHz) - Highly efficient antennas are available in this frequency range and with the resultant low power requirements, very small, lightweight radio tags can be fabricated. Additionally, VHF scanning and data processing equipment have been developed to identify individual transmitters. and collect telemetry data, and automated data collection and remote station capabilities are already in the development process. There are, however, two drawbacks to using VHF for tracking at this time: 1) there is no ADF which will work effectively with the low power output from standard VHF transmitters, and 2) surface VHF reception is highly limited to line-of-sight and may be affected by sea state. There is also some evidence that low-level inversions over cold water may block VHF propagation entirely for periods of time.

There are currently three possible attachment/deployment systems for VHF transmitters: the barnacle and umbrella stake tags developed by Bruce Mate and the whale tag developed by Erich Follmann. Each of these tags is small and lightweight, but because the transmitters lie on the surface of the whale, they are subject to dislodgement or crushing. The umbrella stake tag has the best antenna orientation of any tag available but is restricted in use to quiescent whales. The barnacle tag can be deployed on moving whales but presently has limited deployment range (S m in this study) and potentially poor antenna orientation. Although Follmann's tag is less liable to dislodgement and crushing than the other two tags and deploys at a greater distance (up to 10 m), very poor antenna orientation and detuning due to antenna contact with the whale severely limit the theoretical range of the transmitter.

Satellite systems (401.2MHz) - Satellite-1inked systems can track animals and gather data over vast and inaccessible areas at relatively low cost. As fuel costs rise, this will be an ever increasing advantage over other tracking systems for long term or long distance studies. All satellite animal tracking to date has been accomplished using the Nimbus system, but since the system has passed its operational life expectancy, it is increasingly difficult to be assured of continued operation and reception priority. The newer Argos satellite system offers two, sun-synchronous, polar orbiting location and data collection satellites which have good global coverage, especially in the higher latitudes. The greatest drawbacks to satellite tracking are: that no tags are presently available for whales and that some whale species may not surface often enough during certain behavior modes to insure location by the orbiting receivers. However, a whale transmitter is being developed and the location probabilities are being calculated for various whale species under this contract.

In conclusion, it seems clear that the tracking of free-ranging large cetaceans is well within the realm of technological feasibility. The method of tagging and tracking will be dependent upon the objectives of a given study and upon the species to be studied. To insure operational systems, the following tests and developments should proceed:

1) The development and testing of a VHF-ADF for surface vessels and aircraft.

2) The development and testing of an automated data collecton unit with hard and soft copy capability for HF and VHF.

3) Inclusion of the automated data collection units in remote stations (capable of data storage for up to two weeks) for monitoring coastal species.

4) The development and testing of HF and VHF telemetry capability, initially for environmental monitoring (temperature and depth) followed by physiological monitoring (heart beat, blood pressure, core temperature).

5). The development and testing of a high-gain, HF-ADF antenna for aircraft.

6) Laboratory and field studies of rejection mechanisms designed to gather data which will suggest developments to increase longevity of tags.

7} The development and testing of an Argos satellite-linked location transmitter following the current processor-controller development.

8) Continued development and testing of attachment mechanisms concurrent with data acquisition in the OCS.

BOWHEAD TAGGING AND TRACKING

Introduction

In June 1978 BLM entered into an Endangered Species Section 7 consultation with the National Marine Fisheries Service (NMFS) to determine the impact of the proposed Beaufort Sea oil and gas lease sale on the endangered bowhead and gray whales. In August of that year, NMFS recommended studies to BLM that would fill the data gaps identified during the consultation. One type of study recommended was the "timing of movements and offshore distribution of bowhead and gray whales through the proposed lease sale area and adjacent waters." NMFS also recommended studying the "overall movement patterns of bowhead and gray whales in the Beaufort Sea." Although the general pattern of migration is known for bowhead whales (Braham et al., 1980; Braham and Krogman, 1977; Fraker, 1979; Fraker et al., 1978), the specifics of migratory timing, movements, and habitat use are largely unknown and lend themselves to study by radio tracking. With the successful tracking of radio tagged gray whales along their migratory path for up to 95 days (Mate, 1979), a test was needed to determine the feasibility of tagging and tracking bowhead whales in order to fill the data gaps identified in the Section 7 consultation. In addition to determining the feasibility of finding, approaching, and tagging bowhead whales, this study sought to determine longevity of the tags, effect of the tags on behavior, dive/surface profiles, and movement patterns of bowheads in the vicinity of the Northern Alaska OCS lease sale areas.

Study Area

For these initial tests a study area was chosen which would afford the maximum probability of locating bowhead whales in ice-free waters of the Beaufort Sea, where the animals could be approached easily by surface vessel and tagged without ice nearby on which to dislodge the surface-mounted transmitters. It was also imperative to have an accessible logistical base with an airfield and supplies. After studying whaling and sighting records (Bodfish, 1936; Cook, 1926; Fraker and Bockstoce, 1980; Hazard and Cubbage, 1980; Ward, 1979) and interviewing researchers who had worked in the Beaufort Sea (Braham, Fraker, Sergeant, Sterling, pers. commun.) the village of Tuktoyaktuk was chosen as the logistical center because of the high probability of locating concentrations of whales between Cape Perry on the east and Herschel Island on the west. The relocation area encompassed the entire Beaufort Sea from approximately 125°W longitude near Cape Perry, Northwest Territories, Canada to 155°W longitude near Point Barrow, Alaska and offshore to approximately 72″N latitude (Fig. 1). This area included the North Slope OCS lease sale from 146° to 154°W longitude.

Field Preparation

Since the contract for this work was not signed until mid-May and field work had to commence by mid-July, an immense effort was required to perform the necessary logistic arrangements. In addition to procurement of all necessary field gear, a biotechnician had to be hired, a vessel chartered, aircraft coordination arranged, video and still photography equipment tested, U.S. and Canadian permits acquired, attachment mechanisms and radio transmitters manufactured and tested, transportation and coordination of participants arranged, and all gear packed and shipped to the Northwest Territories.

Of prime importance was the testing, alteration, and fabrication of the radio tags. The tag types chosen for this experiment were developed and thoroughly field tested by Bruce Nate on gray whales (for description see Mate, 1979; Mate, 1980). These barnacle and umbrella stake tags (Fig. 2) had, however, never been tested on any other cetacean species. Therefore, frozen blubber blankets were acquired from bowhead whales taken in the annual Eskimo harvest, and although the blubber samples could not accurately portray _in vivo_ tissue responses, tests were undertaken to stimulate the effects of the two tags on bowhead tissue and the effectiveness of the holdfasts relative to gray whale tissue.[1] The tags were tested and altered and retested over a six-day period with the following results:

Barnacle tag - The maximum distance for proper deployment and antenna orientation of barnacle tags was initially calculated to be approximately five meters. Thus, all test tags were fired from five meters into pieces of bowhead blubber without the skin but with the fascia and were extracted with a spring scale to give a relative indication of holding power of various configurations. Video tape recordings were made of test firings to allow instant reevaluation. Initial tests showed that deployment by a drug immobilization rifle (Zulu Arms, Omaha, NE; Fig. 3)[2] was superior in speed and accuracy to deployment by a compound bow (Bear Archery, Gainesville, FL; Fig. 4)[2], that the new teflon tine retaining rings worked well, and suggested the following modifications and further tests: 1) place barbs on the tines to add greater holding power, 2) further deform tines before loading to create more flare, 3) file base of tines to help them further deform upon entry, and 4) dissect out shots to determine deformation _in situ_. Further test shots and dissection indicated that the addition of barbs and the further deformation of the tines before loading contributed significantly to the holding

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[1] Special thanks for the blubber samples to Tom Albert, Erich Follman, Gordon Jarrell, and the whaling captains who gave them tissues.

[2] Utilization of trade names does not imply endorsement by the National Marine Fisheries Service.

power of the tags and that filing the bases of the tines made no difference. Thus, the barnacle tags for the field experiments (Fig. 5) were fabricated with flaring tines, barbs, teflon retaining rings, 7.5 cm by one meter Saflag visual streamers (Safety Flag Co. of America)[1] and the S2B5 transmitter and antenna (Telonics, Inc.)[1] tested by Mate.

Umbrella stake tag - Early tests of this tag deployment system (see Fig. 6) indicated that the stakes were not seating against the base plate nor deforming when entering bowhead tissue as they had on gray whale tissue. These tests suggested the addition of barbs to the umbrella stake tines to increase holding power and further testing to determine if the stakes were not seating because of bounce back or because of lack of power for penetration. When barbs were added to the tines of stakes they universally seated on the baseplate and required well over twice as much force to dislodge (Fig. 7). Subsequently, barbs were added to all stakes for the field exercises.

The receiving system was identical to that used by Mate (Telonics TR-2 receiver, TS-1 scanner, TDP-2 processor, and DF receiver)[1]. However, rather than rely on individual frequencies for unique identification of each tagged animal and run the risk of missing a signal from a tag during a frequency scan, as many transmitters as possible were tuned to one frequency and the individual transmitter was identified by the time between pulses.

The success of the tagging project depended on our ability to find and approach bowhead whales at quite close range and then to radio track

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[1] Utilization of trade names does not imply endorsement by the National Marine Fisheries Service.

them from the surface and from the air. The 48-foot motor vessel, Pressure Ridge (Fig. 8) was chartered for the study. People familiar with bowhead whales in the Arctic (Burns, Silook, Steen, pers. commun.) felt that working in an aluminum boat with outboard motor from the Pressure Ridge would allow approach to within five meters of whales for tagging with either the barnacle or umbrella stake tags. A 16 ft Lund Aluminum[1] boat was purchased (and shipped to Tuktoyaktuk) with a variety of outboard motors and was modified for two sets of oars so that various methods of approach could be tested. A satellite navigation system was leased for Pressure Ridge to assure accuracy of sighting locations and vessel position.

To insure the availability of a dedicated and reliable aircraft for relocation of radio tagged whales, arrangements were made to have the Grumman Goose[1] already surveying for bowhead whales in the Beaufort Sea under contract to BLM, modified to carry two, side-leaking, high gain, two-element yaggi antennas and two whip antennas for direction finding (DF) capability (Fig 9.) The Goose was made available periodically through the summer in the eastern Beaufort and then again in the fall in the central and western Beaufort for reconnaissance and for relocation effort. In addition, mounts for side-looking, high gain antennas were fabricated for aircraft of opportunity and small charter aircraft (one set for high wing Cessnas (Fig. 10) and one set for Twin Otters).[1]

Because the bowhead whale is considered highly endangered and because the issues surrounding its continued existence are both

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political and volatile, it is to the advantage of all parties to cooperate closely in any endeavor to gather information germane to these issues. Toward this end, the Alaska Eskimo Whaling Commission (AEWC) and the Canadian Government were requested to participate in this research. Arrangements were made for travel and accommodations so that representatives could acquire direct knowledge of the methods and results of this research. In addition, a trip was made to Tuktoyaktuk to confer with the village Hunters and Trappers Association regarding the proposed research.

In order to provide BLM with photodocumentation of the research and to provide the field party with a very useful tool for instantaneously evaluating research protocol and whale behavior, a portable video tape unit was tested for field use. Video taped sequences could be used to compare normal bowhead behavior to the behavior of tagged whales, to document tag condition over time, and to record whale reaction to tagging, both for alteration of methods in the field and for later evaluation. Still photos were taken of all phases of preparation and field activities.

Field Activities

Beginning July 17, the Office of Aircraft Services (OAS) in Anchorage modified the BLM whale survey platform, a turbine Grumman Goose, for aerial radio tracking. After installation and testing of the antennae and receiving equipment in Anchorage, aerial surveys for bowhead whales were flown enroute to Tuktoyaktuk along the Alaska and Canadian Arctic coasts (Figs. 11, 12}. Gray whale and walrus sightings were numerous along the west coast of Alaska on July 20 and beluga whales were sighted in Alaskan and Canadian coastal waters on July 20 and 21; no bowhead whales were sighted on either day of the survey. Further surveys were flown on July 22 and 23 to locate bowhead whale concentrations in the eastern Beaufort Sea. In seven and one-half (7 1/2) hours of flight along the Tuktoyaktuk Peninsula, Baillie Islands, and in Liverpool and Franklin Bays, only one possible bowhead sighting (70°37.5'N x 129°50.6'W) was made in addition to sightings of ringed and bearded seals and beluga whales moving predominantly southwest toward the Mackenzie River Delta (Figs. 13, 14). Before the Goose returned to Alaska on July 24, all radio receiving systems were tested and calibrated, and the survey crew was given instructions in the use and care of the aircraft receiving equipment.

On August 3 the charter vessel, Pressure Ridge, left Tuktoyaktuk Harbor completely outfitted for 15 days at sea, searched for bowhead whales reported along the Tuktoyaktuk Peninsula and then continued on to the vicinity of Baillie Islands where whaling records indicated the abundant occurrence of whales in early August (Fraker and Bockstoce, 1980). The scientific party consisting of Larry Hobbs, Michael Goebel, and Roger Silook (AEWC)(the representative of the Canadian government was required to return to Winnipeg just prior to our departure) spent four days searching as far east as Franklin Bay and recorded only one unconfirmed bowhead whale sighting (Fig. 15).

The Pressure Ridge returned to Tuktoyaktuk to solve radio communication problems and to determine the location of whale concentrations reported by the “Effects of Human Disturbance” team (LGL, Ltd., Mark Fraker, Principal Investigator). Bruce Mate came aboard to replace Roger Silook.

Between August 9 and 11 bowhead whales were encountered on two occasions and in both cases tagging attempts were abandoned after a short time because of heavy fog (Fig. 15). Whales encountered during this time were moving quite rapidly and could only be tagged with the ballistically deployed barnacle attachment, since umbrella stake tags can only be attached to relatively sedentary whales. Bowheads were approached in the aluminum skiff at high speed as was advised by native hunters, but each time the skiff came within about 30 m, the whales sounded. In no instance was it possible to maneuver within tagging distance. Video recording had to be abandoned because all participants of the reduced crew were needed for the tagging process. Foul weather then forced the Pressure Ridge back to Tuktoyaktuk Harbor on August 11.

On August 13 the Goose returned to Tuktoyaktuk to survey-the nearshore waters and to determine the distribution of whales. Systematic surveys were flown parallel to the Tuktoyaktuk Peninsula on August 14 and thirty whales were sighted between Warren Point and Cape Dalhousie (Fig. 16). Subsequently, survey and search flights were flown (Figs. 17-26) to determine any change in distribution and to direct the tagging team to areas of maximum whale concentration. An analysis of that data will be forthcoming in a separate report. While in Tuktoyaktuk awaiting good weather, a barnacle tag was tested on a beluga whale, Delphinapterus leucas, killed in the native fishery (Fig. 5). The tag deployed very well and is recommended for radio attachment for that species.

Between August 16 and 19 the Pressure Ridge rode at anchor "at Tuft Point and could not work because of bad weather conditions. The survey crew in the Goose sighted 166 bowhead whales during this time

(Figs. 17, 18). On August 19 the vessel charter was terminated by mutual agreement and the tagging team transferred from Pressure Ridge to a shared charter with an NMFS research team aboard the sailing vessel Ungaluk.

On the morning of August 20, the Ungaluk (Fig. 27) set sail to search for whales along the Tuktoyaktuk Peninsula. During that afternoon whales were sighted in the vicinity of Warren Point (Fig. 28) and tagging was attempted from the aluminum boat, again using the outboard motor. Various approach angles and speeds were tested but only one approach came near firing range (about 10 m), and the shot taken with a barnacle tag fell well short of the whale. After three hours the fog closed in and further tagging attempts were only possible from the Ungaluk. Quiet approach by sail worked well and at 2330 hours (69°54'N x 132°12'W) barnacle tag number 135 with a white streamer was placed on a 35 foot bowhead (Fig. 29). The animal had rolled on its side and the transmitter was implanted midway down the left upper body, too low for transmission on each surfacing. When tagged, the whale kept rolling in its sounding dive without changing speed or thrashing flukes. Signals were received intermittently for ten minutes and then lost.

Because of the successful tag placement under sail, it was decided to attempt further quiet approaches by rowing the aluminum boat rather than using the motor. On August 21 (for cruise track see Fig. 30) barnacle tag number 137 with a yellow streamer was successfully placed on a 40 ft. bowhead whale using the rowing technique (Fig. 29). After the tag implanted, the whale continued to lay at the surface for about four seconds, twitched its skin, and slowly swam away. The Goose was surveying in the area (Fig. 20) and was able to receive signals from the tagged animal until it ran low on fuel, about 1 1/2 hours after initial radio contact. The dive/surface data collected at that time from tag number 137 (Fig. 31) was contaminated to an unknown extent by radio transmissions at the same frequency from Ungaluk and the tagging skiff. The receiving range from the Ungaluk, which should have been 15 miles, had deteriorated since previous tests to less than two miles; and by the time faulty antenna connectors were identified and repaired, the whale had disappeared and signals were not received again. Later that day, a barnacle tag shot missed a bowhead at close range. There was no visible reaction to the discharge or to the tag striking the water about two meters beyond the whale.

On August 22 the Goose aerial survey team searched for the tagged whales and then returned to Alaska for a required 100 hr service. For the next three days (Figs. 32-34), the scientific party aboard Ungaluk searched for large concentrations of whales but the bowheads seemed to be spreading out and moving west rapidly. One group of juvenile whales (approximately 30 feet in length) surfaced repeatedly within about 50 m of the aluminum boat, but the skiff was too heavy and awkward to be rowed fast enough to reach them before sounding. However, dive/surface profiles were collected from animals identifiable by natural scar patterns, and one profile was compared to the radio transmissions from tag number 137 '(Fig. 31).

Although large numbers of whales were seen along the Tuktoyaktuk Peninsula between 25 and 27 August by LGL and NMFS scientists, the Ungaluk, which had run aground on August 25, was unfit to return to sea.

On August 30 the Goose attempted to fly to Tuktoyaktuk but was forced to return to Deadhorse because of weather. No whales were sighted on that flight between Prudhoe Bay and Herschel Island (Fig. 22). Surveys conducted on August 31 and September 3 and 4 indicated that bowhead whales had dispersed from the Tuktoyaktuk Peninsula (Figs. 23-26) and no large concentrations were found (10 sightings of 20 bowheads). Flights between September 4 and 12, however, sighted large concentrations of whales 30 to 50 miles off the Tuktoyaktuk Peninsula. On 12 September 25 sightings of 37 whales were made from an aircraft chartered to relocate tagged bowheads (Fig. 35). Despite extensive monitoring from the Goose, the LGL chartered aircraft and a chartered Skymaster, no transmissions were received from tagged whales in the eastern Beaufort Sea after August 21 and no vessel was available for further tagging after August 24.

The essential tagging gear was shipped west aboard the Goose on September 13 when the opportunity arose to attempt tagging in the central Beaufort Sea in the vicinity of Beaufort Lagoon. An Alaska Department of Fish and Game (ADF&G) team had been able to approach a few bowhead whales in a 21 ft. Boston Whaler there during the second week in September, but by the time the tagging effort began on September 14th, severe ice conditions had set in and only a few unsuccessful attempts to locate whales were possible (See Fig. 36). The Goose was used to find whales and later to lead the researchers aboard the Boston Whaler through the ice to clearer water so that they could return to Deadhorse. On September 23 they reached Prudhoe Bay, ending attempts to place more radio tags on bowhead whales during the 1980 season.

From September 16 through October 13, however, flights were made in conjunction with the BLM bowhead survey team to relocate the two tagged whales as they passed the North Slope OCS lease sale areas during their fall migration. On one occasion during this time, a brief radio transmission was received but the presence of tagged bowhead whales was unconfirmed by either further transmissions or visual relocation (Fig. 1).

DISCUSSION

As in any first year research in a remote area, logistical problems required an inordinate amount of time and effort and in some cases made it impossible to realize research goals. For example it was not possible to test the umbrella stake attachment or to photo- and videodocument the tagging effort because the scientific party aboard Ungaluk, with two distinct and immiscible research protocols, was too small to accomplish these tasks. The lack of a truly reliable and seaworthy vessel capable of reaching whale concentrations quickly and staying at sea for an extended time was, and remains the predominant problem in working on bowhead whales in the Beaufort Sea. The ideal vessel should be large enough to 1) weather the most severe storms encountered during the summer, 2) carry a crew capable of safe vessel operation around the clock for at least two weeks, and 3) accommodate a scientific party of sufficient size to carry out all facets of the research without undue stress (24 hour watches, tagging, photodocumentation, oversight). Because vessels are extremely expensive in the Arctic ($3,000/day minimum), a smaller, high speed vessel which could house a ship's crew of at least three and a scientific party of at least four might serve as an alternative. Such a vessel could reach whale concentrations quickly during breaks in the weather and run from foul weather as it approached.

The results of this study and some previous studies (for example, Norris, et al. 1976) suggest that aircraft may be ineffective for relocating radio tagged cetaceans except in very special circumstances such as populations with highly defined migratory pathways or confined home range. The problem arises from the interpretation of negative data (i.e., does "no signal" mean the animal was not in the area covered by the aircraft, the transmitter had fallen off, the animal did not surface while the aircraft was within range, or the antenna angle precluded signal reception?) and the low probability of encountering a given cetacean in the relatively small area possibly searched by an aircraft. The latter problem is compounded when the relocation effort is combined with aerial surveys since transmission reception is cut by 2/3 to 3/4 at the lower altitudes necessary for visual sightings. Distance trials using a test transmitter showed that the Goose flying at 1,000 ft. received signals over about a 40 mile swath (213 miles on each side) and received signals over about a 140 mile swath flying at 8,000 ft. Thus , a signal could be detected from a given point on transect (e.g. , a surfacing whale) for one hour and ten minutes at 120 knots from 8,000 ft, while at 1,000 ft. the aircraft would pass out of contact with that point in 20 minutes. Although far greater than surface vessel coverage capability, the relocation area covered by aircraft at reasonable cost, even at high altitudes, is quite small compared to the area of habitat available to highly mobile or non-coastal migrating cetaceans.

Some of the problems of aircraft location are solved if remote stations can be used to collect activity pattern, movement, and migration data from radio tagged individuals. Remote stations, however, are appropriate only for certain coastal species where a significant portion of a migratory population passes within range of the receiving antenna or where tagged individuals remain within range of the receiver for a prolonged period. Since this research sought to gather data on the coastal movements of bowhead whales, a contract was awarded for a prototype self-contained, portable, automated data collection unit which could scan a selected number of frequencies at variable scan rate and reliably record time, frequency, and pulse interval for any received pulses over a two-week period. Also, since the amount of data collected during a shipboard radio tracking study can be prodigious, the automated data collection unit, which will code and store information on computer-compatible magnetic tape as well as hard COPY (ticker tape), should greatly facilitate data reduction. Unfortunately, due to a supplier delivery failure, the prototype unit was not available for testing during this field season but should be ready for use by late spring, 1981.

The greatest difficulty in tracking whales using VHF radio tracking systems has been the lack of an ADF capable of giving an instantaneous directional readout of short pulse VHF signals without tremendous gain loss and thus greatly diminished tracking distance. Before truly successful, operational shipboard and aircraft VHF radio tracking can proceed, a VHF-ADF must be available which is comparable to that developed by Martin et al.(1971) for lower frequencies (HF).

As Mate (1980) pointed out, identifying individual transmitters with unique frequencies adds to the problem of aerial reacquisition since an animal on the surface might be missed during a receiver frequency scan even while within reception range. In order to alleviate this problem in this study, as many transmitters as possible were placed on the same frequency and individually identified by a unique interpulse Interval as measured by a pulse analyzer (Telonics, Inc.)[1]. This system insured no loss of reception due to a frequency scanning but had three major drawbacks: 1) three clear, strong pulses must be received to determine interpulse interval and therefore identity, and three pulses may not be received due to poor antenna orientation or short surface time; 2) the interpulse interval may vary over time in the field, although laboratory tests demonstrated stability to within 10 milliseconds; and 3) confusion can easily develop while tracking a tagged whale if another tagged whale is nearby or a transmitter is accidentally actuated as was the case on August 21, 1980. If frequency scanning is to be used in the future, a locking scanner would would clearly facilitate tracking. The modified scanner would hold onto an incoming signal so that the tracker knows which frequency to monitor on the following whale surfacing.

One of the goals of this research was to determine the response of bowhead whales to tagging. From previous experience with spaghetti tagging whales and capturing and handling a variety of large and small cetaceans, no adverse reaction to tagging was anticipated. Additionally, Mate (1979, 1980) observed very little reaction to the placement of umbrella stakes or barnacle tags on gray whales and even noted continued “friendly”’ or curious behavior after tagging. In reviewing thirteen tagging attempts with the WHOI/OAR whale tag on three species of whale, Watkins (In press) describes short term whale reaction to vessel maneuvering but almost no reaction to tagging, per se. Others who have used the WHOI/OAR tag had reported some

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short-term behavioral disturbance and suggest that tagged animals are perhaps "more wary than usual of approaching boats" (Anonymous, 1977; Jim Johnson, Pers. Commun.). The reactions observed in the bowhead tagging study did not differ from those previous observations. When approached by motorized vessel, bowheads generally showed some sign of avoidance. However, when approached quietly, by sail or by oar, only the slightest reaction to tagging was noted.

The reason or reasons for loss of signals from the two tagged whales remains largely unknown. Certainly the antenna cable connector shorts were partially responsible for the signal loss aboard *Ungaluk*. However, it is useful to speculate on two other possibilities: 1) the signal may have been lost due to low level inversions over the cold water (Watkins discontinued using VHF frequencies for radio tracking for this reason), and 2) although it seems very unlikely because of complete deployment, the transmitters may have been dislodged immediately by the whales. Further tests involving simultaneous tagging with HF and VHF frequency transmitters should determine the relative effectiveness and efficiency of each frequency as well as test for effectiveness of attachment and the effect of possible inversions upon signal reception.

In conclusion, the bowhead whale tagging program experienced mixed success. One of the major goals of the research, the determination of the feasibility of open ocean tagging of bowhead whales without harm to whales or taggers was completely realized and successfully accomplished and the logistical fabric for future work in the Beaufort Sea was, established. In addition, this research suggests that 1) the use of aircraft for primary relocation of wide ranging, tagged whales is generally inappropriate, 2) a VHF-ADF for shipboard and aircraft tracking must be developed, and 3) further bowhead tracking requires a suitable vessel with crew and scientific party of sufficient size and dedication to insure success. Both barnacle and umbrella stake tags deployed and held well in laboratory tests on bowhead blubber, and barnacle tags deployed perfectly in the field trials. Therefore, if a suitable vessel could be acquired, there is great likelihood that a very successful tagging and tracking program is possible with bowhead whales.

Satellite-linked Transmitter Development

In the past few years there has been a dramatic increase in the use of tracking technology as a tool for filling the information gaps in the life histories of free-ranging large cetaceans. Because of the high cost and often overwhelming logistical considerations involved in radio tracking cetaceans by ship and aircraft in the open ocean, responsible agencies and scientists have shown great interest in the development of satellite-linked tracking and data collection. In the early 1970's, NASA funded the initial development of electronic gear and attachment methodology for satellite tracking free-ranging whales, but the program was discontinued before fruition. In 1977 new interest was sparked in the possibility of satellite-linked tracking with the U.S. Fish and Wildlife Service's successful use of The Nimbus 6 satellite to track a free-ranging polar bear for over one year. At the same time NMFS began a program for gathering data on porpoise stocks in the eastern tropical Pacific via satellite and undertook the development of a Nimbus 6-linked transmitter which could be fitted to the dorsal fin of oceanic small cetaceans. Each new transmitter development has drawn on the experience of former development efforts and incorporated state-of-the-art electronics.

New and improved radio tag attachments for large cetaceans renewed interest in satellite tracking whales and BLM funded a developmental program for satellite-linked transmitters. The integration of a new-generation, programmable processor-controller unit as the control center for transmission frequency stability, encoding reliability, and timing in the transmitter will cut power requirements and therefore allow reduction of total transmitter size and weight so that components can be packaged in existing radio tracking housings for large cetaceans (i.e., WHOI/OAR tag, barnacle tag, umbrella stake tag). A three phase development was proposed to produce and test an engineering model and six pre-production models within one year. By early July it was evident that the processor-controller development was going to be delayed until the spring of 1981 and that concurrent development of other components would be inappropriate until the processor-controller was thoroughly tested. Therefore funds for transmitter development, other than the processor-controller, were immediately returned to BLM for support of other critical research. The progress of the SLT development will be reported to the CO and COAR in a timely fashion and in subsequent reports to BLM.

Bowhead whale dive/surface data gathered by Koski and Davis (1980) and Davis and Koski (1979) from the eastern Canadian Arctic, by Wuersig et al. (1981) and ourselves from the eastern Beaufort Sea, and by Carrel and Smithhisler (1980) from the Chukchi Sea indicate that these whales exhibit a wide variety of activity patterns. Mean dive times range from 3.2 min. to 9.6 min. with large variance and mean surface times range from 1.09 min. to 1.69 min. , again with a large variance. Because there is such a wide variety of activity patterns and such a small sample of dive times, it is impossible to determine their distribution from this data and accurately model the probability of locating an instrumented whale by satellite. It is clear that an accurate estimate can only be obtained with data from radio tracking. The radio tracking profiles collected by Dr. Mate from instrumented gray whales will be analyzed for satellite location probability as soon as the raw data tapes are available. Bowhead whale radio tracking profiles will be collected during the 1981 field season and subsequently analyzed.

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Literature Cited

Anonymous. 1974. Wildlife monitoring program plan. National Aeronautical and Space Administration, Ames Research Center, Moffett Field, California, 72 p.

Anonymous. 1977. Radio tagging of humpback whales - 1977. Report to NMFS in compliance, Marine Mammal Permit No. 136. Marine Mammal Division; Northwest and Alaska Fisheries Center, 7 p. (unpublished manuscript).

Anonymous. 1978. Porpoise tagging progress report. Prep. for NMFS Southwest Center by National Fisheries Engineering Laboratory, Southeast Center July 1978.

Balcomb, K. C. 1978. Killer whales (*Orcinus orca*) in Puget Sound. Orca Survey 1977 Final report of a field photographic study conducted by the Moclips Cytological Society in collaboration with the U.S. National Marine Fisheries Service. (Unpublished manuscript).

Balcomb, K. C. 1980. The killer whale, *Orcinus orca*, in Puget Sound. Cetus 2(5):6-7.

Bodfish, H. H. 1936. Chasing the bowhead. Harvard Univ. press, Cambridge, Mass. 281 p.

Braham, H. W., Fraker, M. A., and Krogman, B. D. 1980. Spring migration of the western arctic population of bowhead whales. Mar. Fish. Rev. 42(9-10):36-46.

Braham, H. W., and Krogman, B. D. 1977. Population of the bowhead (Balaena mysticetus) and beluga (Delphinapterus leucas) whale in the Bering, Chukchi and Beaufort Seas. Northwest and Alaska Fisheries Center Processed Report, National Marine Fisheries Service, Seattle Washington. 29 p.

Brown, S. G. 1978. Whale marking techniques. In: Animal marking: recognition marking of animals in research (Stonehouse, B., cd.). Proceedings of the R.S.P.C.A. Symposium, London 1977. pp. 71-80.

Carrel, G. M. and Smithhisler, J. R. 1980. Observations of Bowhead Whales During Spring Migration. Mar. Fish. Rev. 42(9-10):80-85.

Cook, J. A. 1926. Pursuing the whale, a quarter-century of whaling in the Arctic. Houghton Mifflin Co., Boston, 344 p.

Cornell, L. H., Asper, E. l)., Osborn, K., and White, M. J. 1979. Investigations on cryogenic marking procedures for marine mammals. U.S. Mar. Mammal Comm. Rep. No. MMC-76/16.

Craighead, F. C., Craighead, J. J., Cote, C. E., and Buechner, H. K. 1972. Satellite and ground radiotracking of elk. In: Animal Orientation and Navigation (Galler, S. R., Schmidt-Koenig, K., Jacobs, G. J., and Belleville, R. E., eds.). pp. 99-111. National Aeronautics and Space Administration, Washington, D. C.

Darling, J. 1977. The Vancouver Island gray whales. Waters: Journal of the Vancouver Aquarium. 2(1):5-19.

Davis, R. A. and Kosiki, W. R. 1980. Recent observations of the bowhead whale in the eastern Canadian high Arctic. Rep. Int. Whal. Comm. 30:439-444.

Erickson, A. W. 1978. Population studies of killer whales (Orcinus orca) in the Pacific Northwest: A radio-marking and tracking study of killer whales. U.S. Mar. Mammal Comm. Rep. No. MMC-75/10.

Evans, W. E. 1971. Orientation behavior of delphinids: radio telemetric studies. Annals N.Y. Acad. Sci. 188:142-160.

Evans, W. E. 1974. Telemetering of temperature and depth data from a free ranging yearling California gray whale, Eschrichtius robustus. Mar. Fish. Rev. 36:52-58.

Evans, W. E., Hall, J. D., Irvine, A. B., and Leatherwood, J. S. 1972. Methods for tagging small cetaceans, Fish. Bull. 70:61-65.

Evans, W. E., and Sutherland, W. W. 1963. Potential for telemetry in the study of aquatic animal communications. In: Bio-telemetry, the use of telemetry in animal behavior and physiology in relation to ecological problems (L.E. Slater, cd.). pp. 217-224, Permagon Press, New York.

Evans, W. E., White, M. J., Gurevich, V. S., and Norris, J. 1979. The biology of small whales. Office of Naval Research, Contract Rep. No. N00014-77C-0212.

Fisher, J., and Peterson, R. T. 1964. The world of birds. MacDonald, London.

Follmann, E. H. 1980. Biotelemetry (RU379), In: Investigation of the occurrence and behavior patterns of whales in the vicinity of the Beaufort Sea lease area. Naval Arctic Research Laboratory final report for the period October 1, 1978 through November 30, 1979. Prepared for BLM Alaska OCS office, Anchorage, AK., pp. 127-133.

Fraker, M. A. 1979. Spring migration of bowhead (Balaena mysticetus) and white whales (Delphinapterus leucas) in the Beaufort Sea. Can. Fish. Mar. Serv. Tech. Rep. No. 859. 36 p.

Fraker, M. A., and Bockstoce, J. R. 1980. Summer distribution of bowhead whales in the Eastern Beaufort Sea. Mar. Fish. Rev. 42(9-10):57-64.

Fraker, M. A., Sergeant, D. E., and Hock, W. 1978. Bowhead and white whales in the Southern Beaufort Sea. Dep. Fish. Environ. Sidney, B. C., Beaufort Sea Tech. Rep. 4, 114 p.

Galler, S. R., Schmidt-Koenig, K., Jacobs, G. J., and Belleville, R. E., Editors. 1972. Animal orientation and navigation. Science and Technical Information Office, NASA, Washington, D.C. 606 p.

Hazard, K. W., and Cubbage, J. C. 1980. Bowhead whale distribution and abundance in Amundsen Gulf, Northwest 'Territories, Canada, summer 1979. Natl. Mar. Fish. Ser. Rep. submitted to the Int. Whal. Comm., Dec. No. SC/32/PS9, 20 p.

Hobbs, L. and Russell, P., Editors. 1979 . Report on the pinniped and sea otter tagging workshop. January 18-19, Seattle, Wash., 48 p. American Institute of Biological Science, Arlington, VA.

Irvine, A. B., Kaufman, J. H., Scott, M. D., Wells, R. S., and Evans, W. E. 1977. A study of the activities and movements of the Atlantic bottlenosed dolphin, Tursiops truncatus. Rep. to the Mar. Mammal Comm. Contracts MM4AC004 and MM5AC018.

Irvine, B., and Wells, R. S. 1972. Results of attempts to tag Atlantic bottlenosed dolphins (Tursiops truncates). Cetology 13:1-5.

Jennings, J. G., and Gandy, W. F. 1980. Tracking pelagic dolphins by satellite. In: A Handbook on Biotelemetry and Radio Tracking (C. J. Amlaner, Jr. and D. W. MacDonald, eds.). p. 753-755. Permagon Press, Oxford.

Johnson, C. S. 1966. Sound detection thresholds in marine mammals. In: Marine Bioacoustics (w. N. Tavolga, cd.). pp. 247-260, . Permagon Press, New York.

Kanwisher, J. W. 1978. Monitoring free ranging animals. Tech. Rev. (June/July):32-39.

Kasuya, T. , and Oguro, N. 1972. A new tagging method of dolphins. Sci. Rep. Whales Res. Inst. 24:81-85.

Kolz, L. A., Lentfer, J. W. and Falleck, H. G. 1978. Polar bear tracking via satellite. Instrument Society of America 15th annual Rocky Mtn. Bioengineering Symposium and 15th International ISA Biomet. Instrumental Symp. 17-18 April 1978, Ames, Iowa. pp. 137-144.

Koziki, W. R. and Davis, R. A. 1980. Studies of late summer distribution and fall migration of marine mammals in NW Baffin Bay and E Lancaster Sound, 1979. Unpubl. Rep. by LGL Ltd., Toronto, for Petro-Canada Explorations, Calgary. 214 p.

Kraus, S., and Katona, S., Editors. 1977. Humpback whales (Megaptera novaeangliae) in the western North Atlantic: A catalog of identified individuals. College of the Atlantic, Bar Harbor, Maine, 26 p.

Kraus, S., and Katona, S. K. 1979. Photographic identification of individual humpback whales (Megaptera novaengliae): evaluation and analysis of the technique. U.S. Mar. Mammal. Comm. Rep. No. MMC-77/17. 29 p.

Lawton, W. S., Towner, M.E., Rice, D. W., and Wolman, A. A. 1981. PISAR - A computerized photo-identification system for humpback whales. Rep. Int. Whal. Comm., Dec. No. SC/31/DOC PS11.

Leatherwood, S., and Evans, W. E., 1979. Some recent uses and potentials of radiotelemetry in field studies of cetaceans. In: Behavior of marine animals, Vol. 3. (H. E. Winn and B. L. Olla, eds.). Plenum Publishing Corp., New York. pp. 1-31.

Mackay, R. S., Editor. 1970. Biomedical Telemetry. Wiley and Sons. New York.

Martin, H. B., Evans, W. E., and Bowers, C. A. 1971. Methods for radio tracking marine mammals in the open sea. Proc. IEEE, Conf. on Eng. Ocean Environ. , Sept., p. 1-6.

Mate, B. 1979. Report to project whales (NARL) on radio tagging of gray whales in Baja Mexico. Oregon State Univ. Mar. Sci. Cen.

Mate, B., 1980. Draft report to the Bureau of Land Management Outer Continental Shelf Program on whale tagging (Contract AA730 79 4120 0109). Oregon State Univ. Mar. Sci. Cen.

Michelson, R. C., Breed love, J., and Jenkins, H. H. 1978. Automated tracking of the Florida Manatee. Final Report Prepared for John F. Kennedy Space Center. NAS10-9097-F.

Mitchell, E., and Kozicki, V. M. 1975. Prototype visual mark for large whales modified from "'Discovery" tag. Twenty-fifth Report of the International Whaling Commission, pp. 236-239.

Nishiwaki, M., Nakajima, M., and Tobayama, T., 1966. Preliminary experiments for dolphin marking. Sci. Rep. Whales Res. Inst. 20:101-107.

Norris, K. S., Dohl, T. P., Guess, R. C., Hobbs, L. J., and Honig, M. W. 1976. Numbers, distribution, and movements in the Southern California Bight. In: Marine Mammal and Seabird Survey of the Southern California Bight Area. Vol. 3(1):270-440. Univ. of California, Santa Cruz.

Norris, K. S., and Gentry, R. L. Capture and harnessing of young California gray whales, Eschrichtius robustus. Mar. Fish. Rev. 36(4):58-64.

Norris, K. S., Goodman, R. M., Villa-Ramirez, B., and Hobbs, L. 1977. Behavior of California gray whale, Eschrichtius robustus in southern Baja California, Mexico. Fish. Bull. 75(1):159-172.

Norris, K. S., and Pryor, K. W. 1970. A tagging method for small cetaceans. J. Mamm. 51:609-690.

Perrin, W. F., Evans, W. E., and HoIts, D. B. 1979. Movements of pelagic dolphins (Stenella spp.) in the Eastern Tropical. Pacific as indicated by results of tagging, with summary of tagging operations 1969-76. NOAA Tech. Rep. NMFS SSRF-737.

Ray, G. C., Mitchell, E. D., Wartzok, D., Kozicki, V. M., and Maiefski, R. 1978. Radio tracking of a fin whale (Balaenoptera physalus). Science 202(3):521-524.

Rice, D. W., Wolman, A. A., and Withrow, D. E. 1979. Preliminary report on gray whale research at Scammon's Lagoon, Baja California, Mexico during the 1979 season. Natl. Mar. Fish. Ser. Rep. submitted to the Int. Whal. Comm., Dec. No. SC/31/DOC.

Scheffer, V. B. 1950. Experiments in the marking of seals and sea lions. U.S.F.W.S. Spec. Sci. Rep. Wildlife No. 4.

Schevill, W. E., and Watkins, W. A. 1966. Radio-tagging of whales. Technical Report Ref. No. 66-17, Woods Hole Oceanographic Inst., 15 p.

Schultz, J. and Pyle, C. 1965. Cat bites whale. Yachting 118(43): 48-50, 92-94, 6 pp.

Sergeant, D. E., and Brodie, P. F. 1969. Tagging white whales in the Canadian Arctic. J. Fish. Res. Board of Canada 26(8):2201-2205.

Stonehouse, B., Editor. 1978. Animal Marking: Recognition marking of animals in research. Proceedings of the R.S.P.C.A. Symposium, 257 p., the MacMillan Press, LTD., London.

Swartz, S. L., and Jones, M. L. 1980. Gray whales, Eschrichtius robustus, in Laguna San Ignacio and its near-shore waters during the 1979-1980 winter season. Draft final report to the National Marine Mammal Laboratory in fulfillment of Contract No. 80-ABD-00009.

Tillman, M. F., and Johnson, J. H. 1977. Progress report on radio-tagging humpback whales. NMFS Processed Rep. 5 p.

Ward, J. G. 1979. Bird and mammal surveys in the Cape Perry Area, Northwest Territories. LGL Limited Report for Dome Petroleum Limited.

Watkins, W. A. 1978. A radio tag for big whales. Oceanus 21(2):48-54.

Watkins, W. A. 1981. Radio tagging of finback whales - Iceland, June-July 1980. Technical Report Ref. No. 81-2. Woods Hole Oceanographic Inst., Woods Hole, Mass. 46 p.

Watkins, W. A. In Press. Reaction of three species of whales to implanted radio tags, _Balaenoptera physalus, Megaptera novaeangliae_, and _Balaenoptera edeni_. Deep-Sea Research.

Watkins, W. A., di Sciara, G. N., and Moore, K. E. 1979. Observations and radio tagging of _Balaenoptera edeni_ near Puerto La Cruz, Venezuela. Technical Report Ref. No. 79-89., Woods Hole Oceanographic Inst., Woods Hole, Mass. 8 p.

Watkins, W. A., Johnson, J. H., and Wartzok, D., 1978. Radio tagging report of finback and humpback whales. Technical Report Ref. No, 78-51. Woods Hole Oceanographic Inst., Woods Hole, Mass. 13 p.

Watkins, W. A., Moore, K. E., Wartzok, D., and Johnson, J. H. In Press. Radio tracking of finback (_Balaenoptera physalus_) and humpback (_Megaptera novaeangliae_) whales in Prince William Sound, Alaska. Deep-Sea Research.

Watkins, W. A., and Schevill, W. E. 1976. Underwater paint marking of porpoises. Fish. Bull. 74:687-689.

Watkins, W. A., and Schevill, W. E. 1977. The development and testing of a radio whale tag. Technical Report Ref. No. 7-58. Woods Hole Oceanographic Inst., Woods Hole, Mass. 38 p.

Watkins, w. A., Wartzok, D., Martin, H. B., and Maiefski, R. R. 1980. A radio whale tag. In: Advanced concepts in ocean measurements for marine biology (F. P. Diemer, E. J. Vernberg, and D. Z. Mirkes, Eds.). pp. 227-241. The Belle W. Baruch Library in Marine Science, No. 10, Univ. of S. Carolina Press, Columbia, s. C.

Woodbridge, D. D. 1978. Potential Use of E.L.F. Radiation for Tracking Manatees. Contract Report to Georgia Institute of Technology, Engineering Experiment Station (Unpublished manuscript).

Wuersig, B., Clark, C. W., Dorsey, E. M., Fraker, M. A., and Payne, R. S. 1981. Normal Behavior of Bowheads. p. 21-90. IN: W. J. Richardson (cd.), Behavior, disturbance responses and feeding of bowhead whales in the Beaufort Sea, 1980. Chapter by New York Zool. Sot. in unpubl. rep. from LGL Ecol. Res. Assoc., Inc., Bryan, Tx., for U. S. Bureau of Land Management, Wash., 273 p.

LIST OF FIGURES

LIST OF FIGURES (continued)

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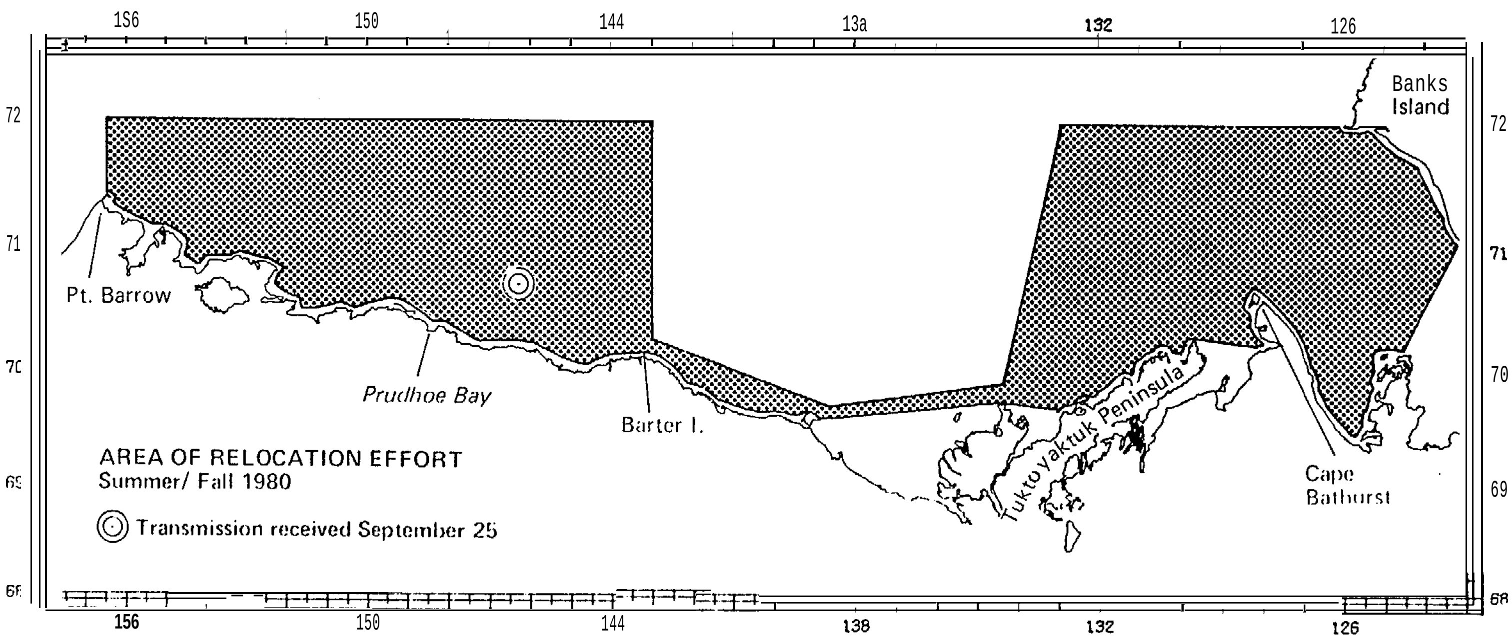
*Each symbol represents one sighting of one or more animals.



1S6
150
144
13a
132
126
72
71
70
69
68
Banks Island
Pt. Barrow
Prudhoe Bay
Barter I.
Tuktoyaktuk Peninsula
Cape Bathurst
AREA OF RELOCATION EFFORT
Summer/ Fall 1980
Transmission received September 25
156
150
144
138
132
126

Fig. 1

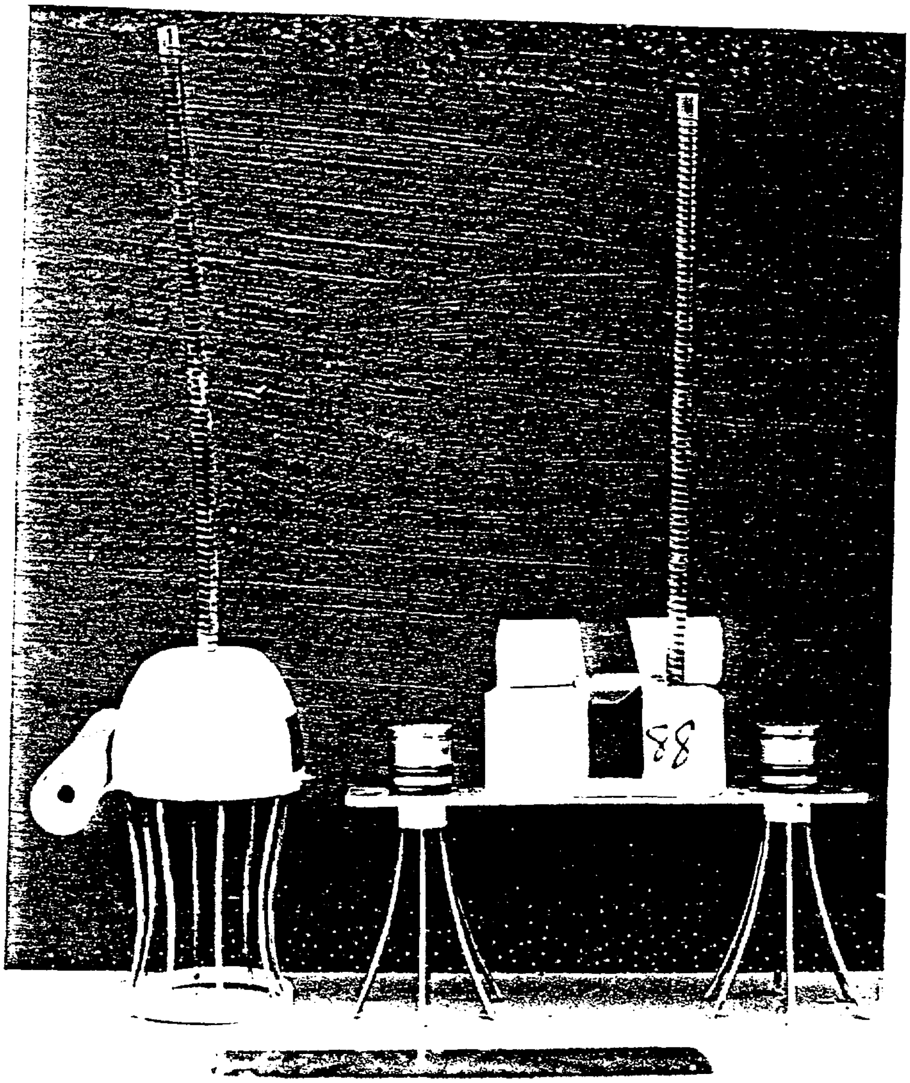
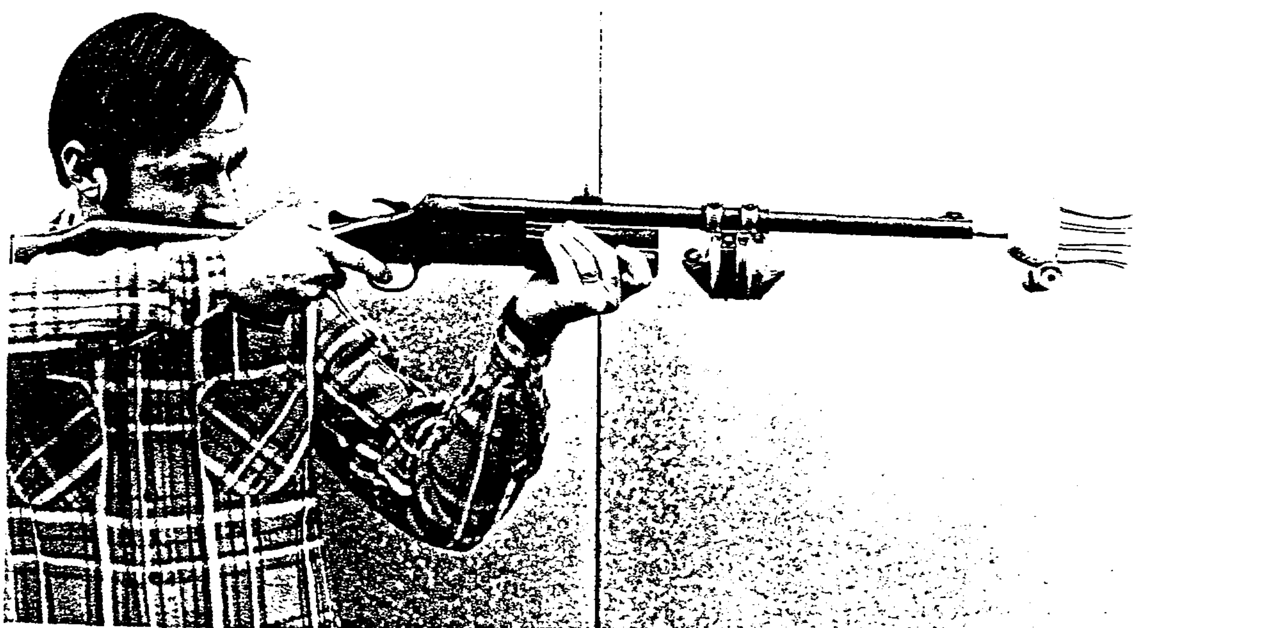
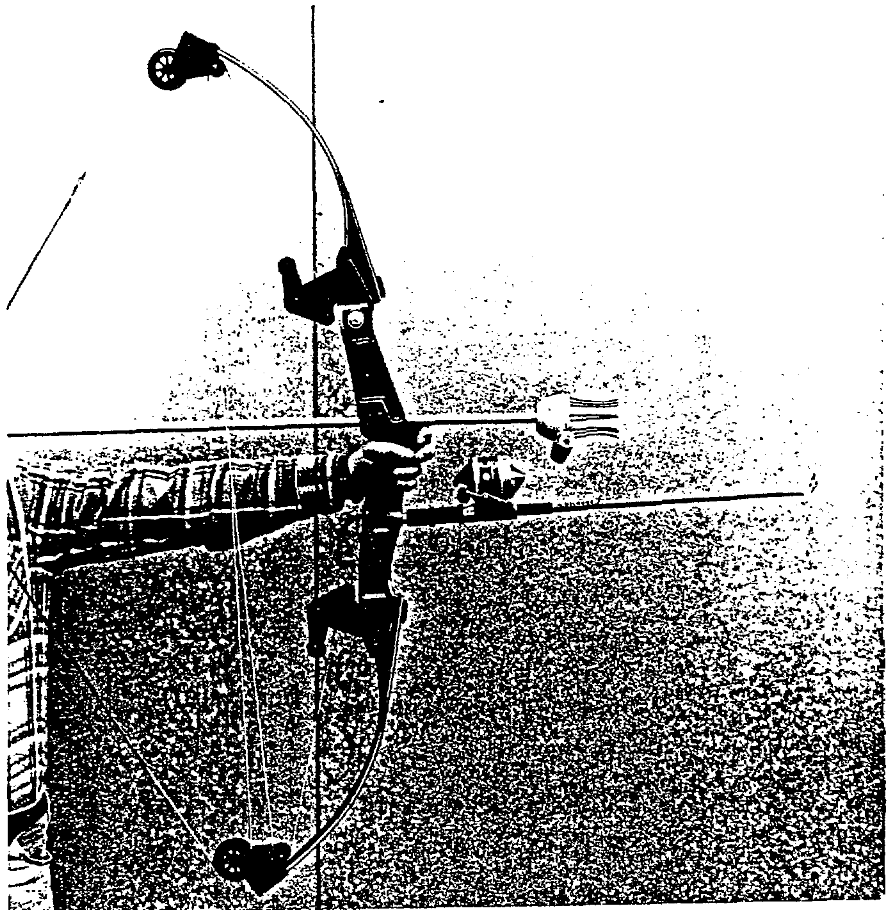
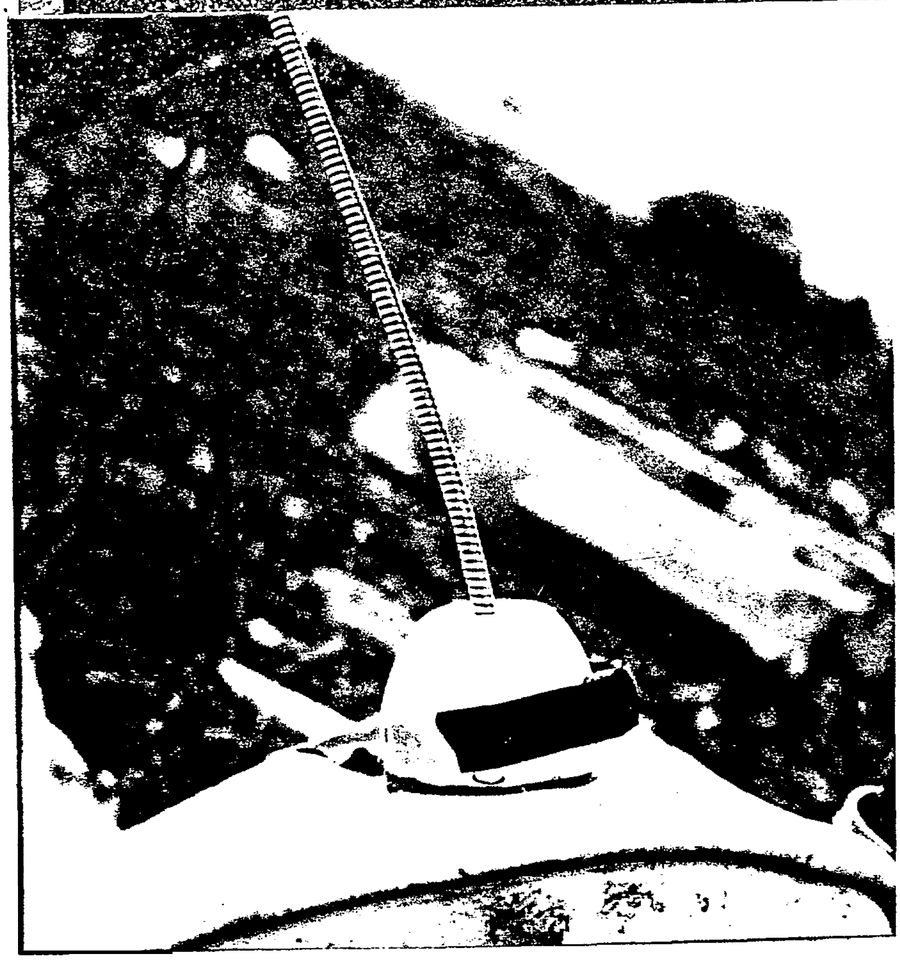


Fig. 2 (left)

Fig. 3 (below)







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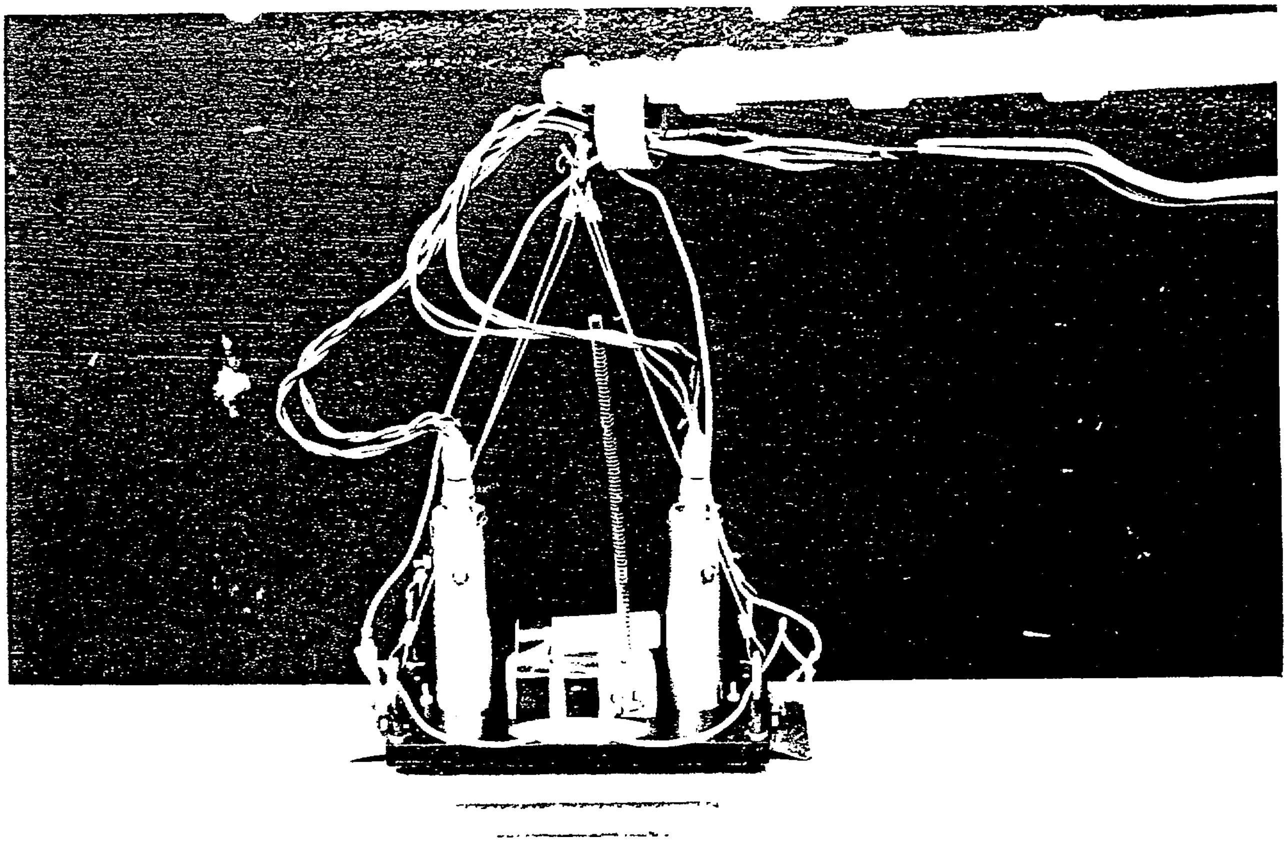

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Fig. 7 (below)

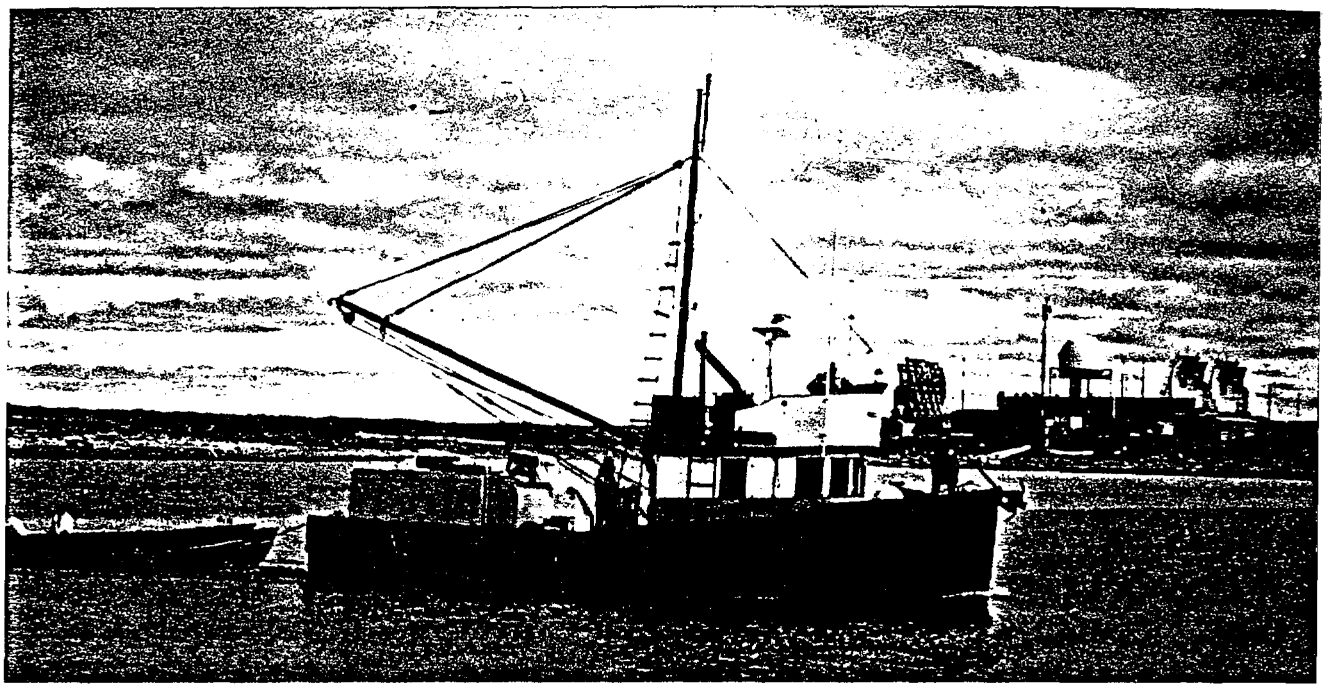

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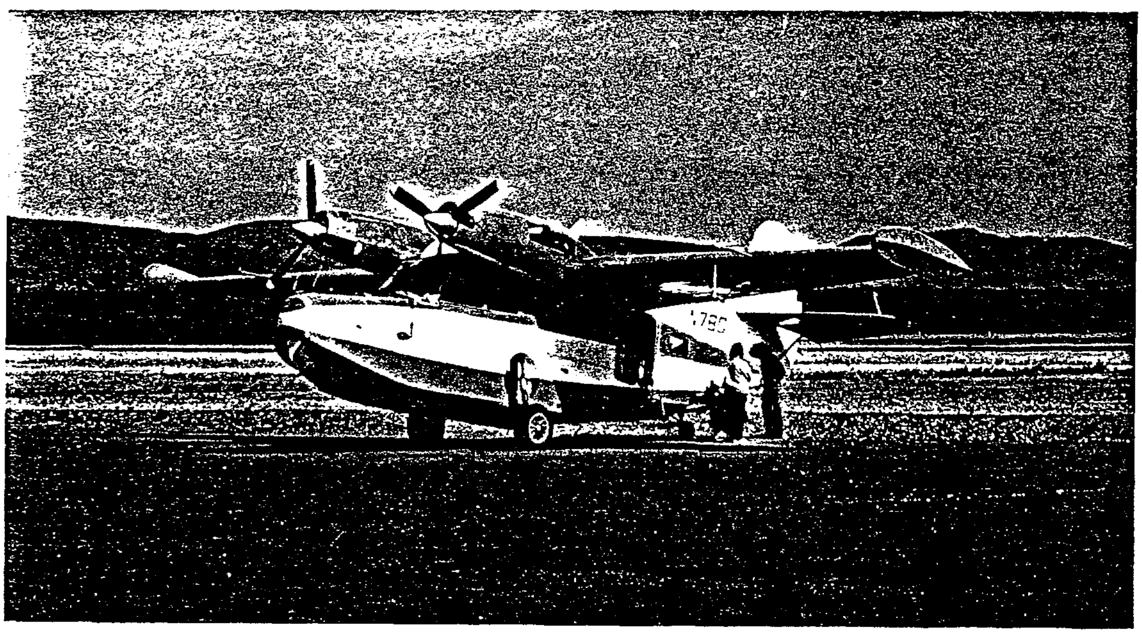
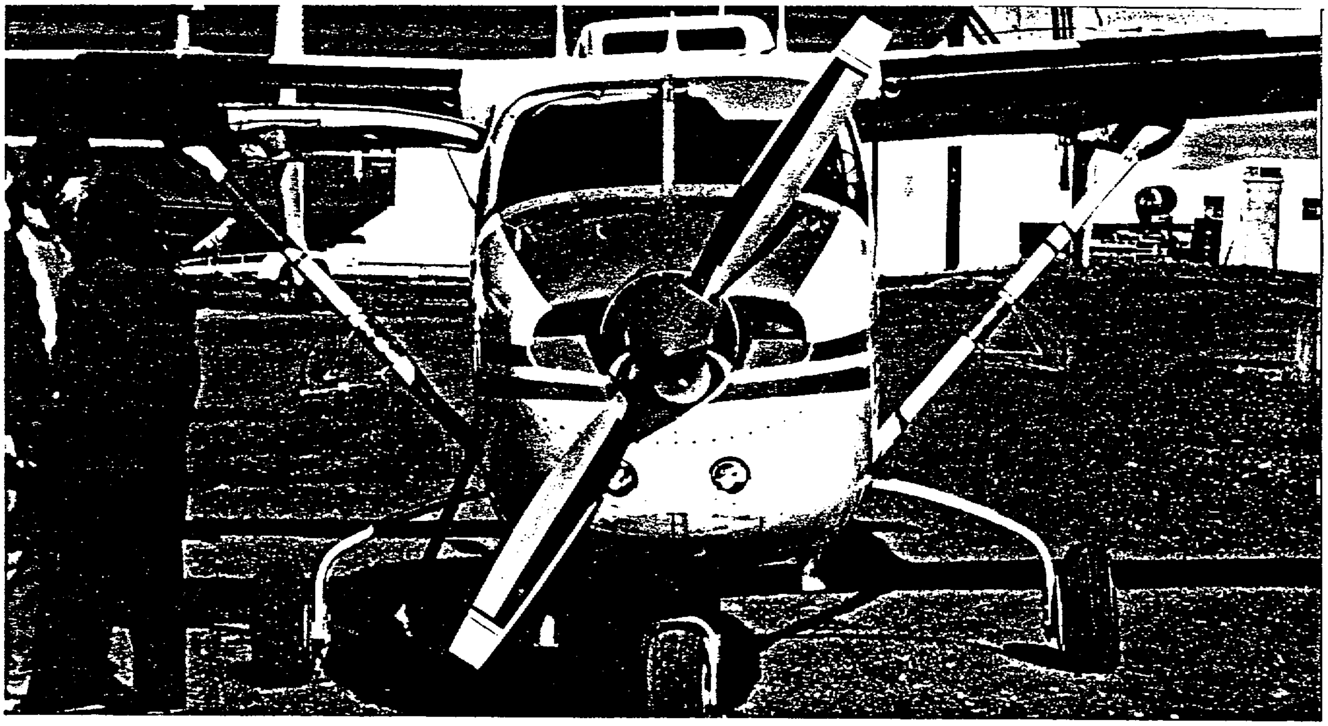
Fig. 9 (below)





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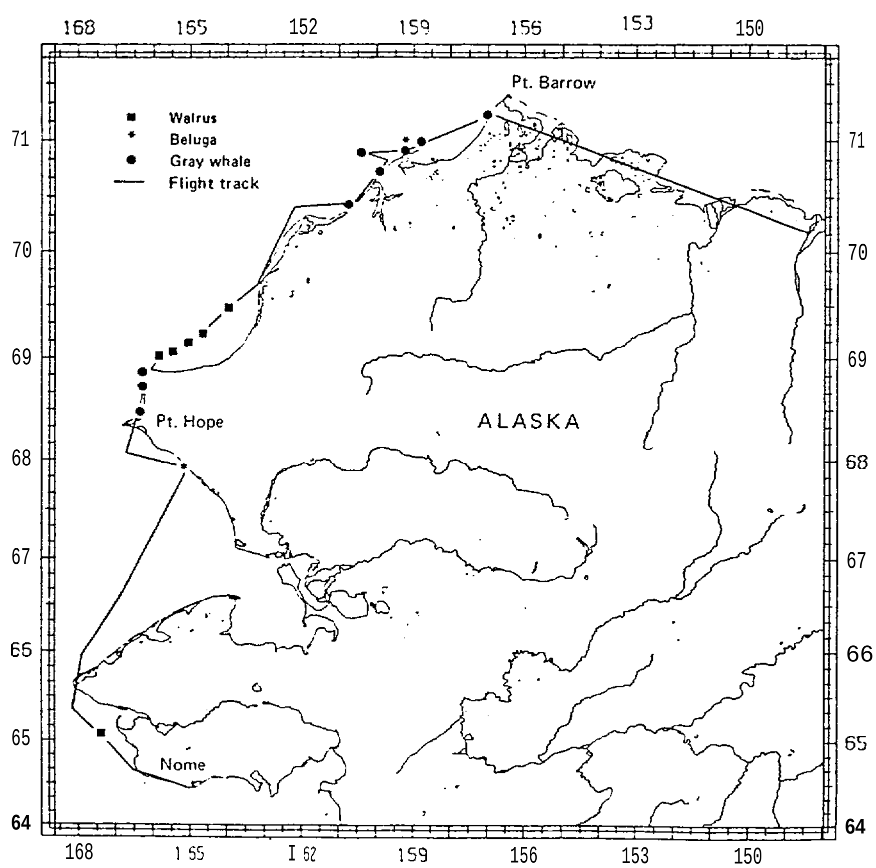

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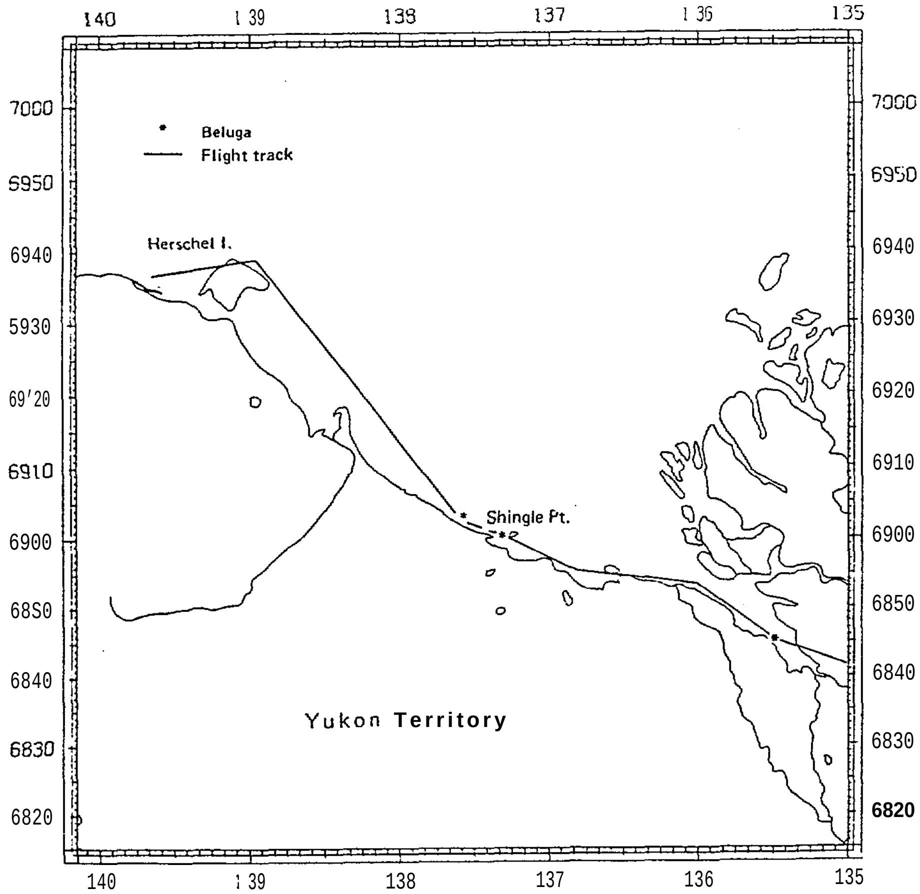

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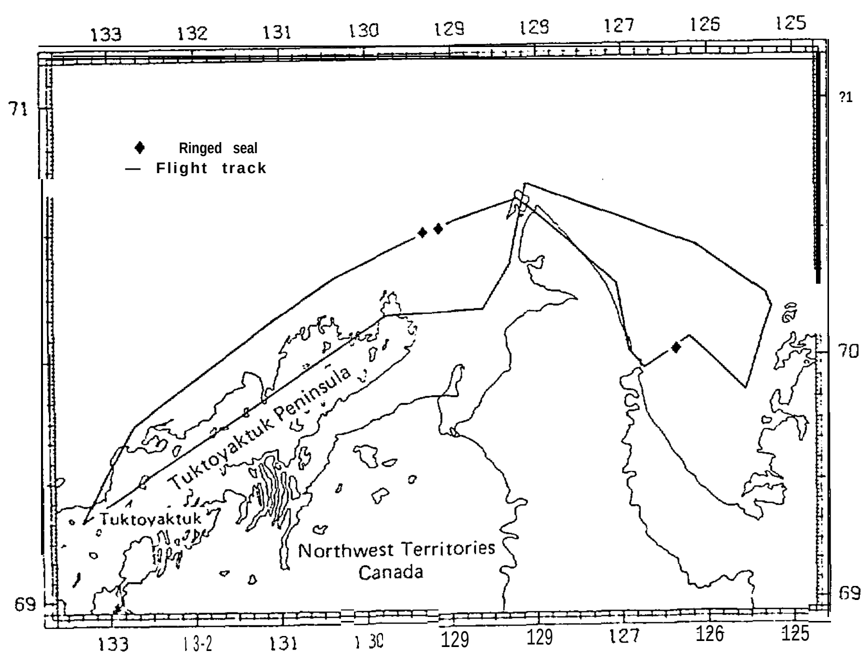
Fig. 13 (below)



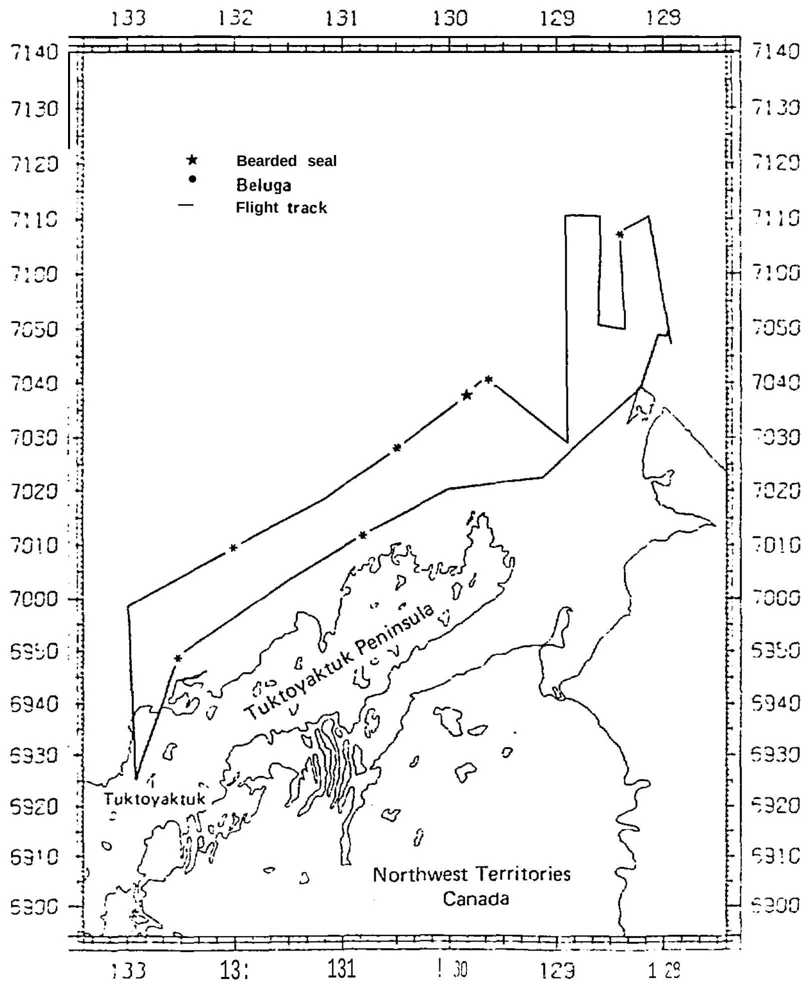


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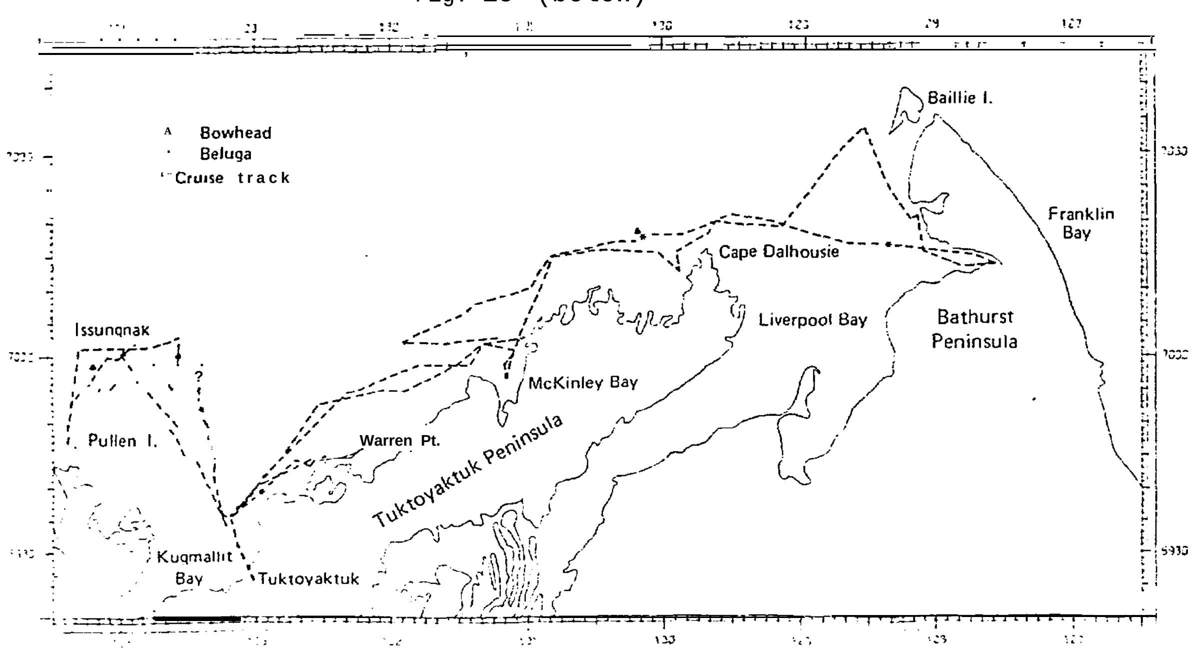
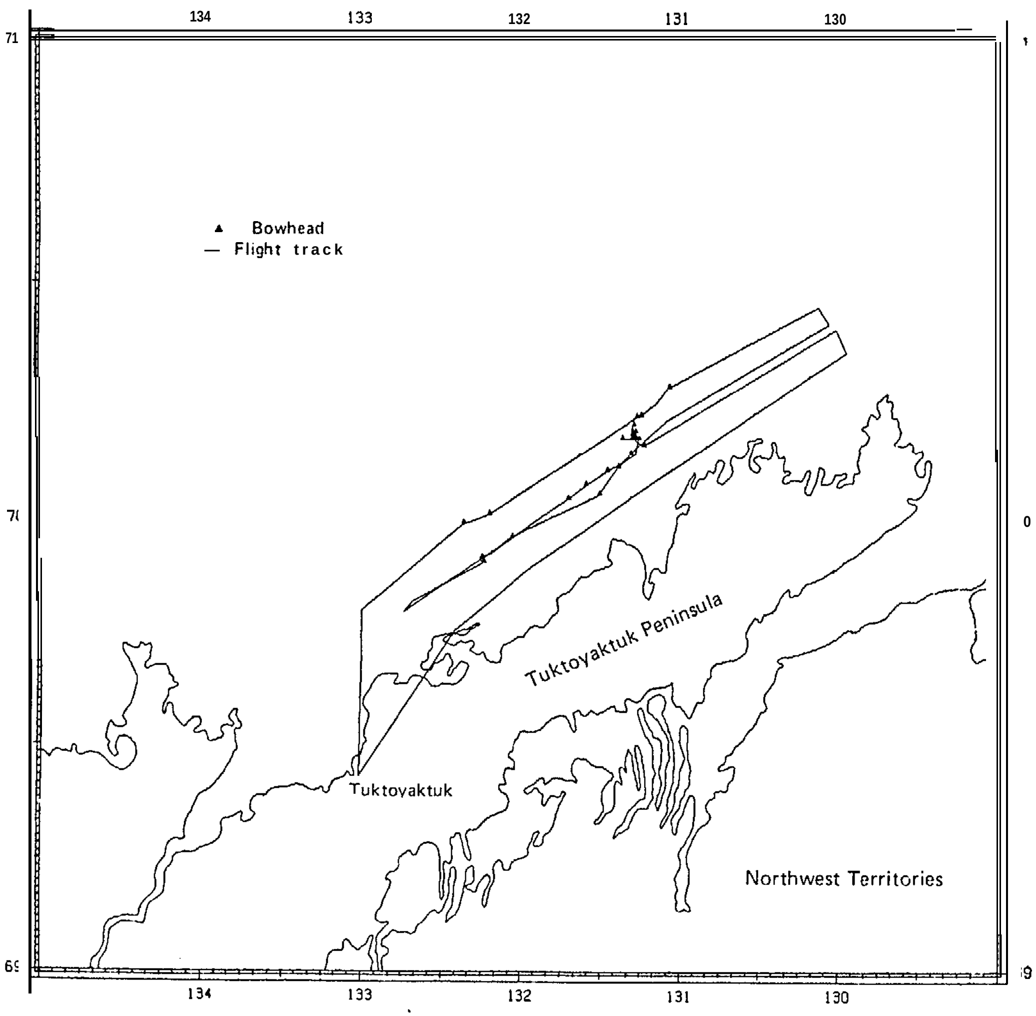
Fig. 15 (below)

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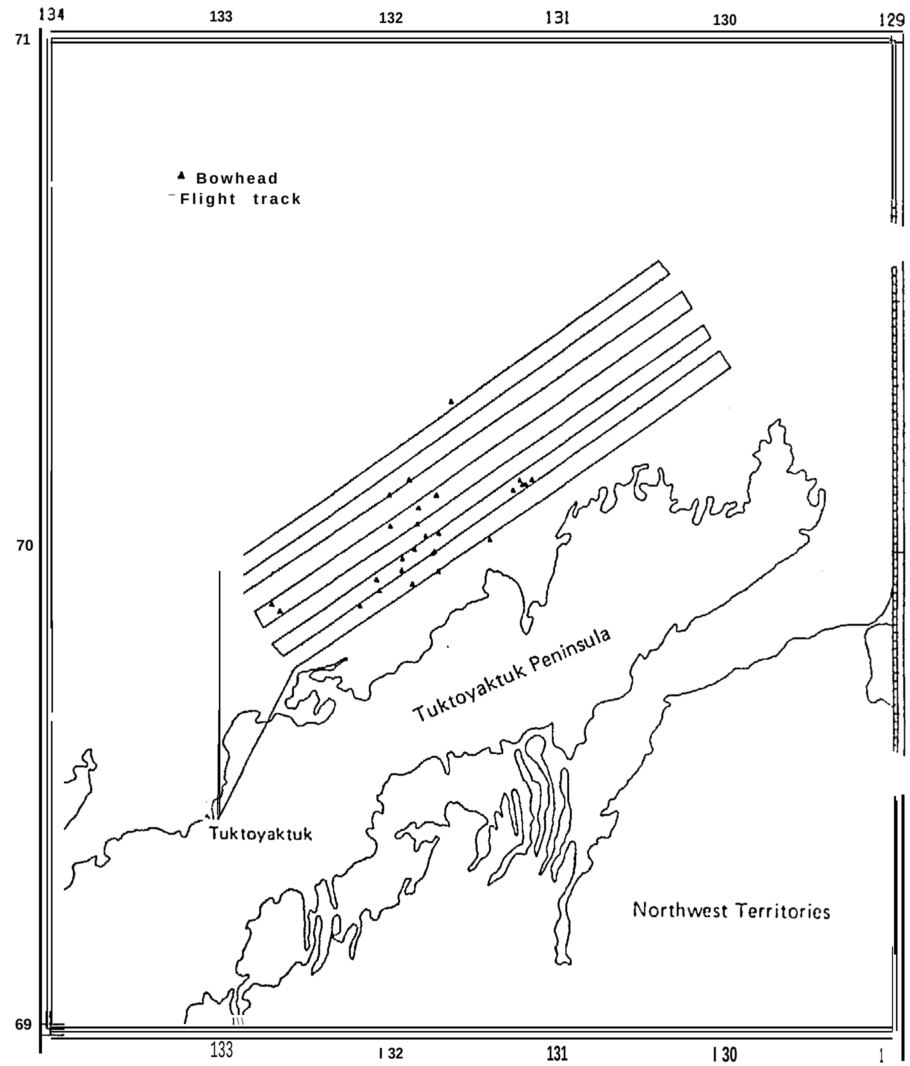
Bowhead
Flight track
Tuktoyaktuk Peninsula
Tuktoyaktuk
Northwest Territories

Fig. 16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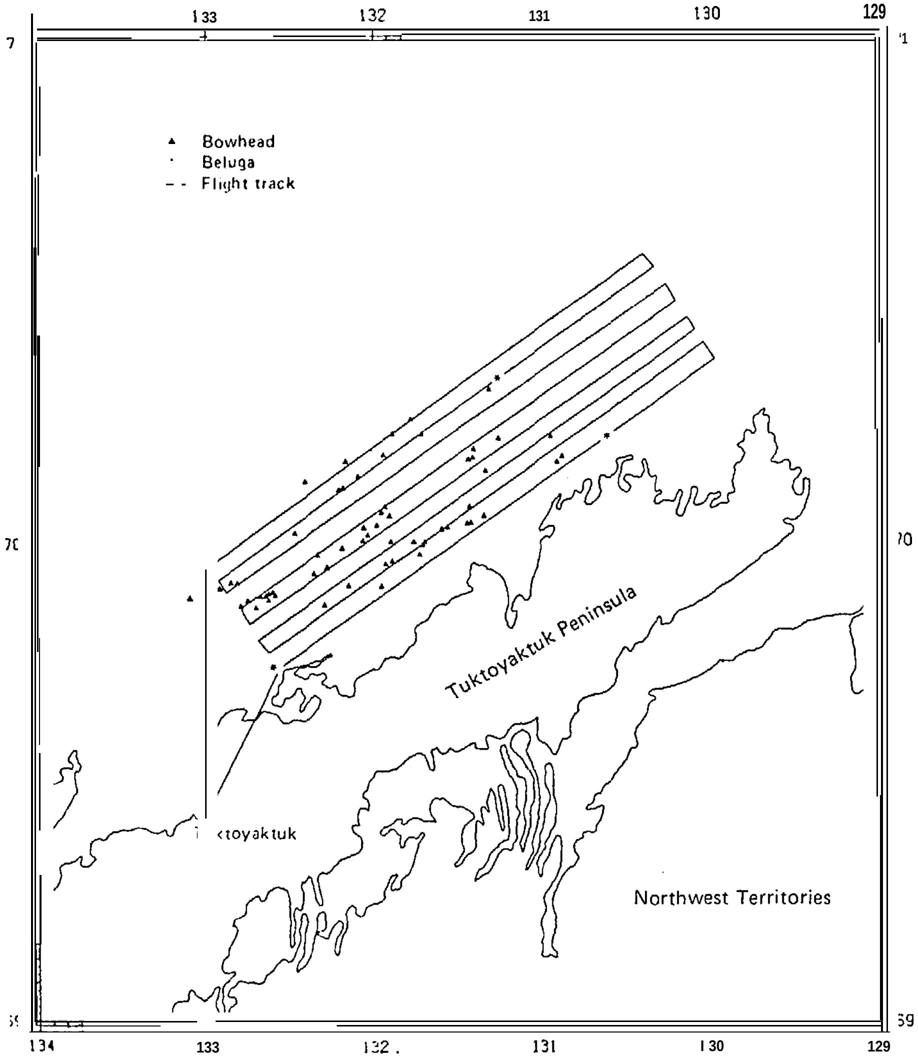
Bowhead
Flight track
Tuktoyaktuk Peninsula
Tuktoyaktuk
Northwest Territories

Fig. 17



133
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Bowhead
Beluga
Flight track
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Northwest Territories
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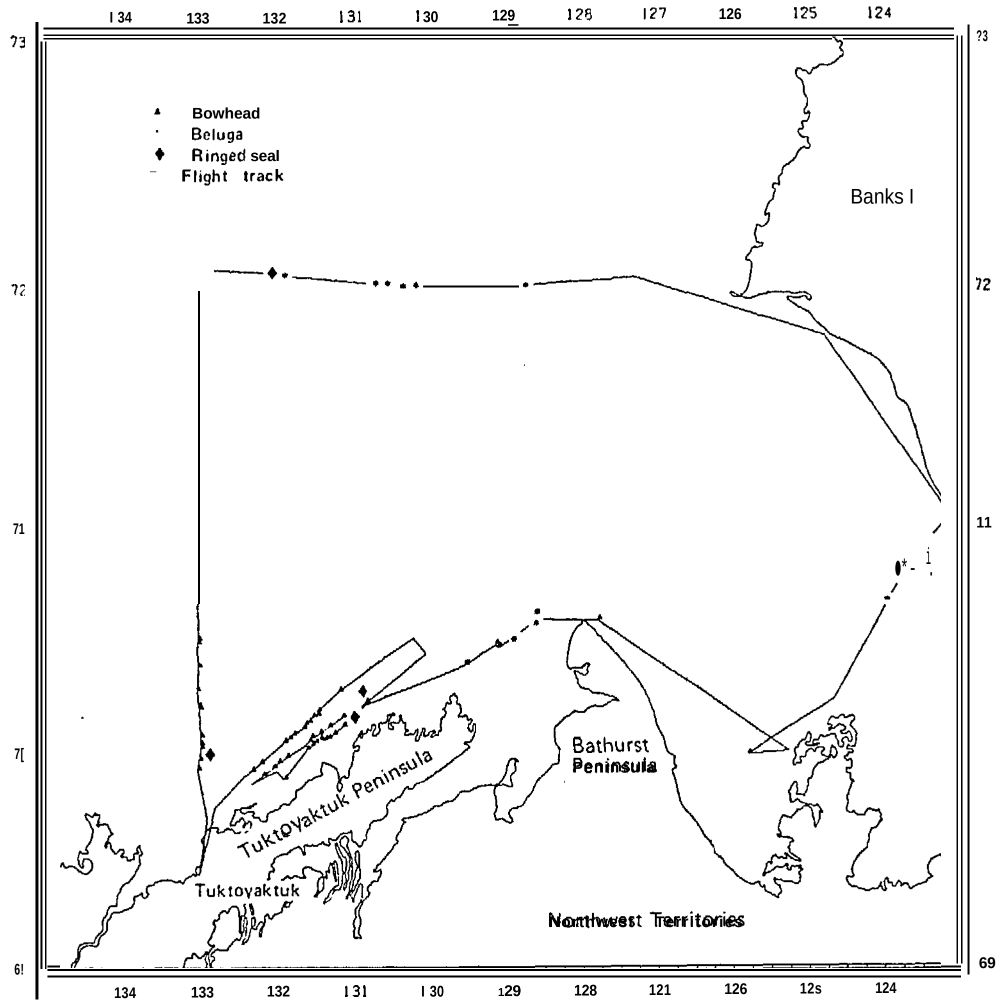
Fig. 18



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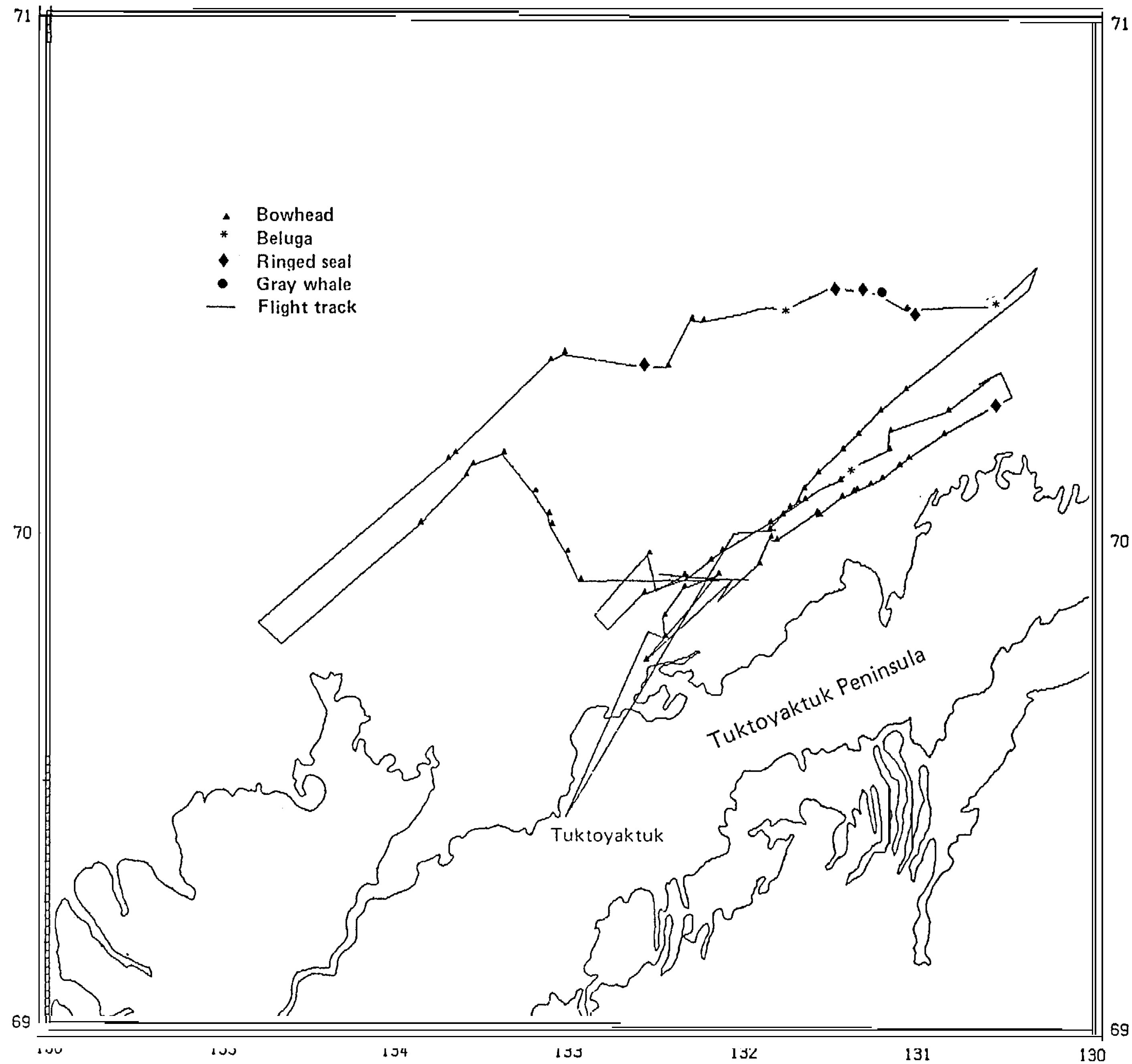
Bowhead
Beluga
Ringed seal
Flight track
Banks I
Bathurst Peninsula
Tuktoyaktuk Peninsula
Tuktoyaktuk
Northwest Territories

Fig. 19



Bowhead
Beluga
Ringed seal
Gray whale
Flight track
Tuktoyaktuk Peninsula
Tuktoyaktuk
71
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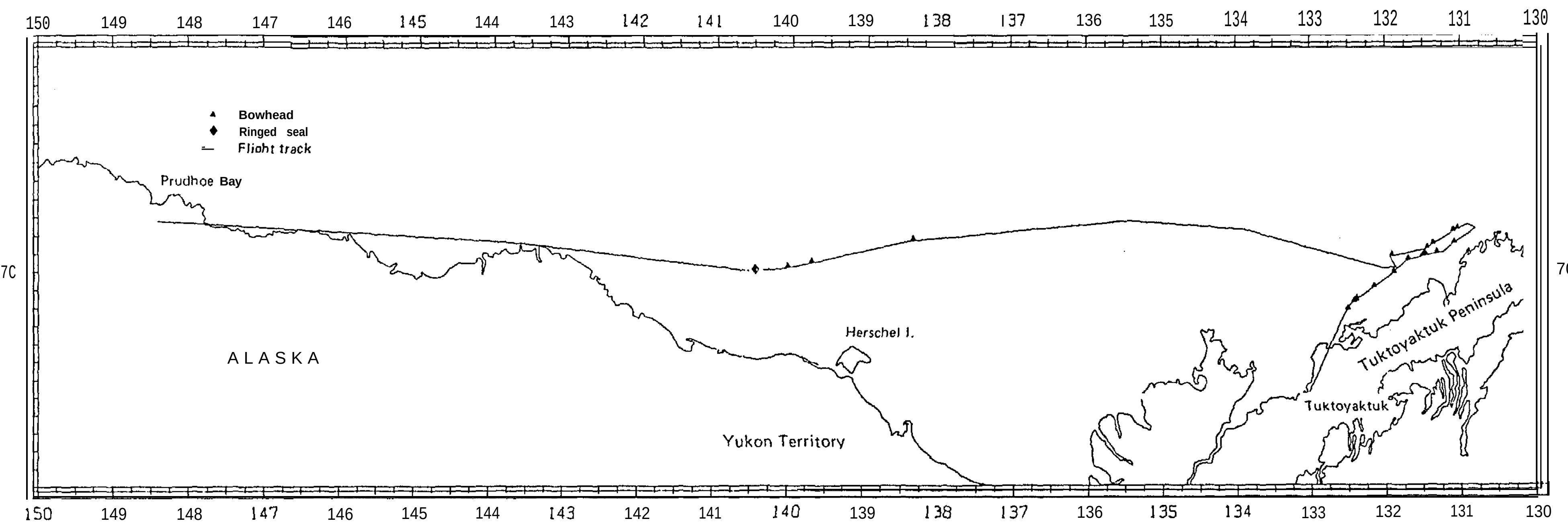
Fig. 2°



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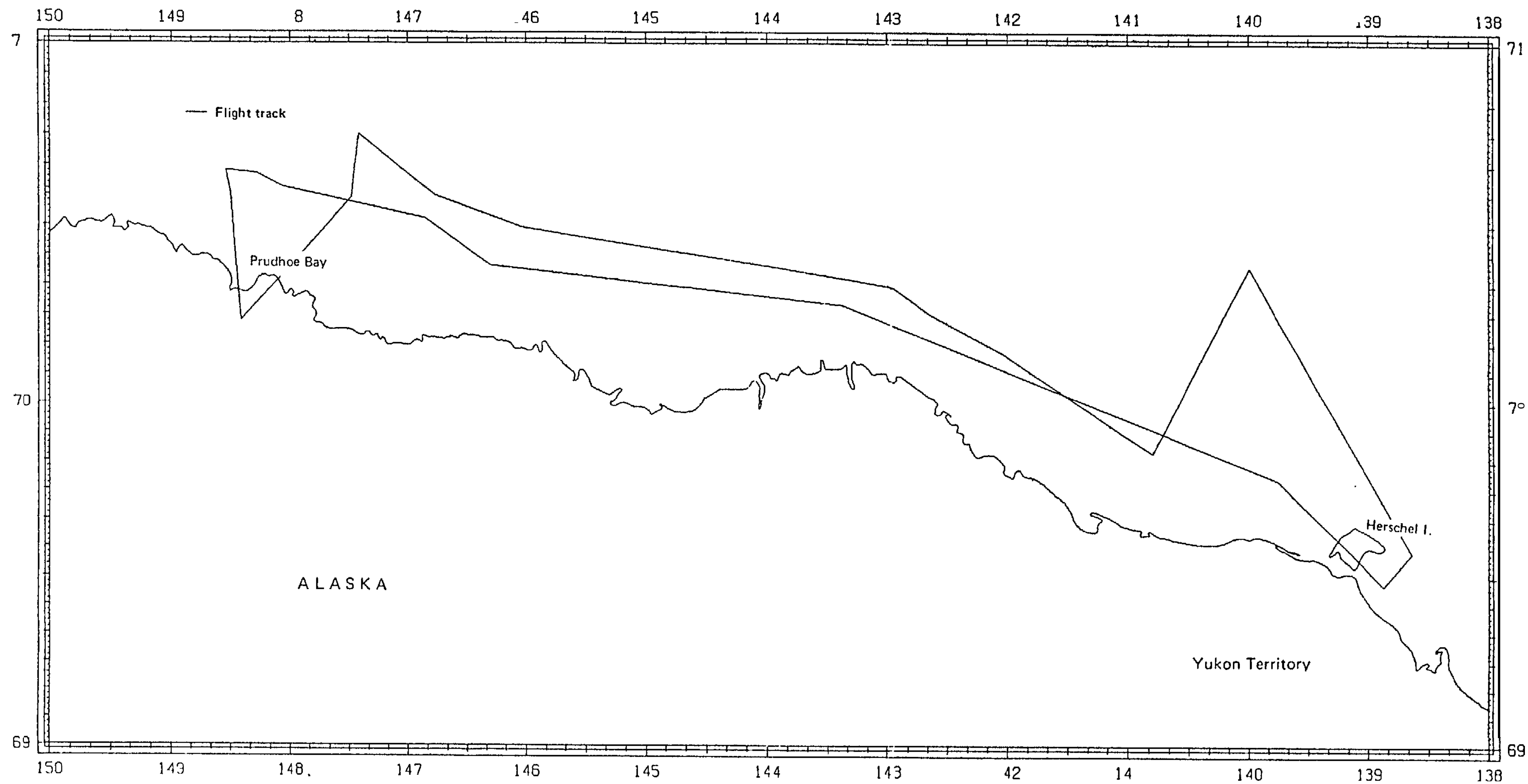
Bowhead
Ringed seal
Flight track
Prudhoe Bay
ALASKA
Herschel I.
Yukon Territory
Tuktoyaktuk Peninsula
Tuktoyaktuk

Fig. 21



Flight track
Prudhoe Bay
Herschel I.
ALASKA
Yukon Territory

Fig. 22

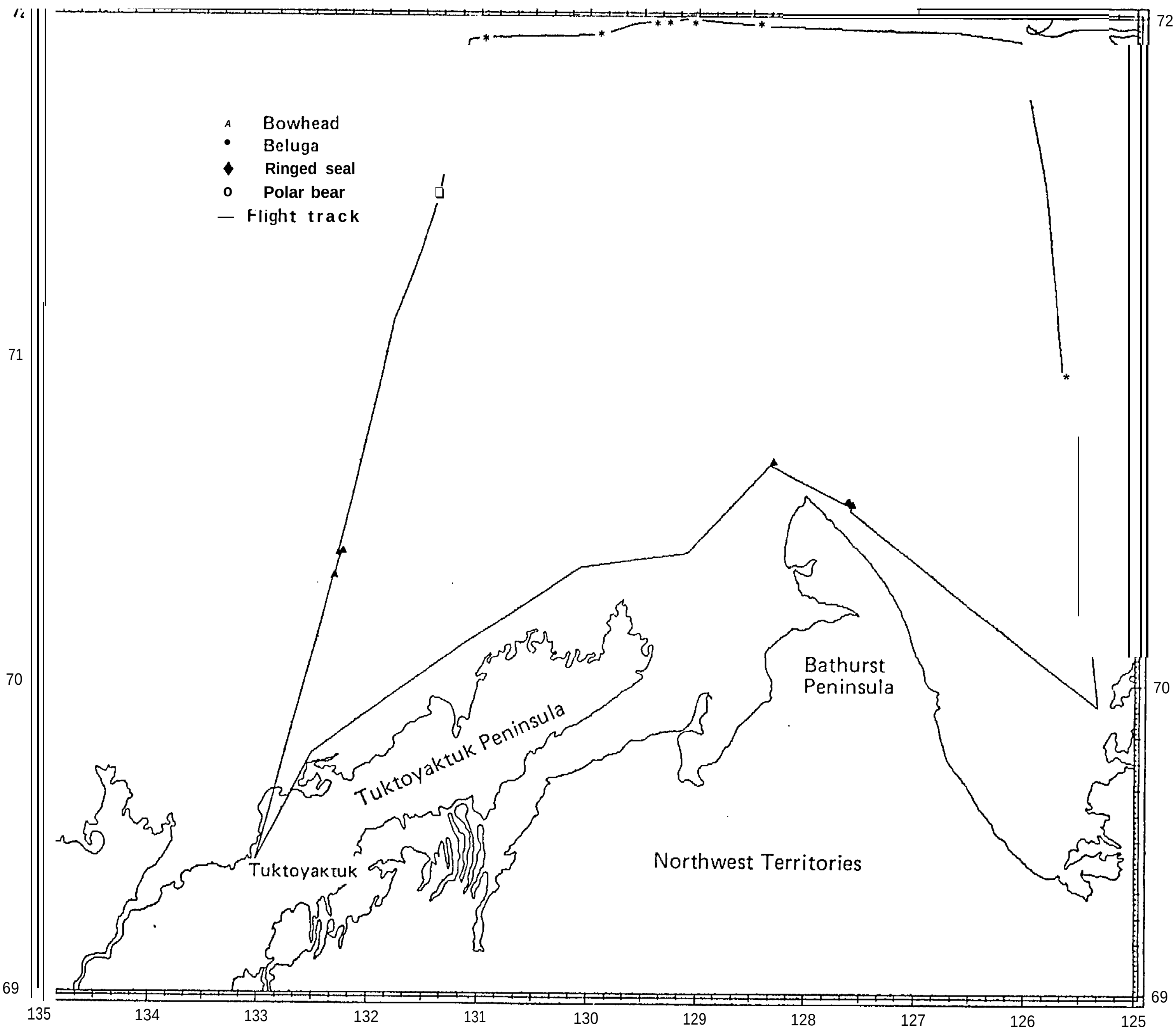

Bowhead
Beluga
Ringed seal
Polar bear
Flight track
Tuktoyaktuk Peninsula
Tuktoyaktuk
Bathurst Peninsula
Northwest Territories
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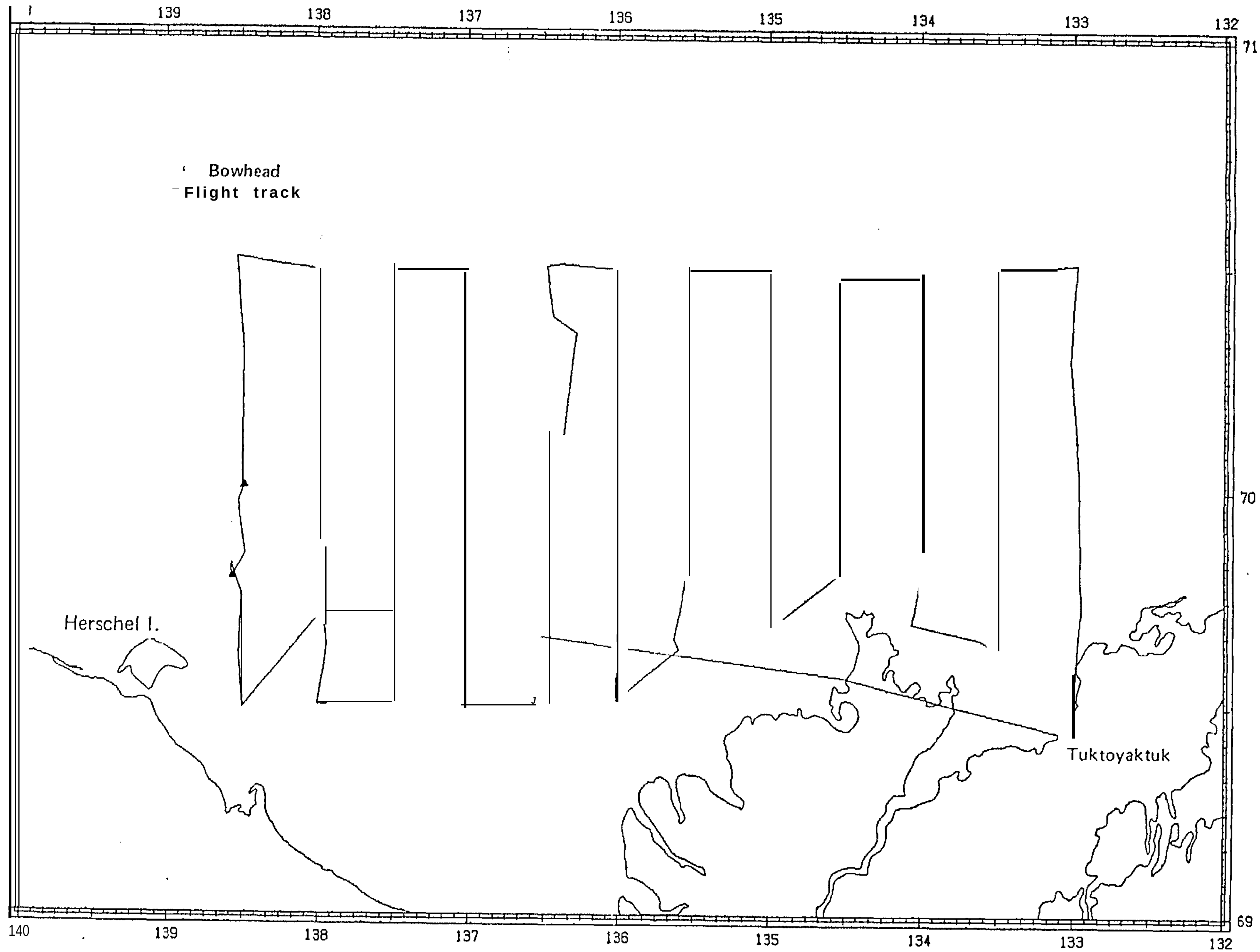
Fig. 23



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Bowhead
Flight track
70
Herschel I.
Tuktoyaktuk
69
140

Fig. 24

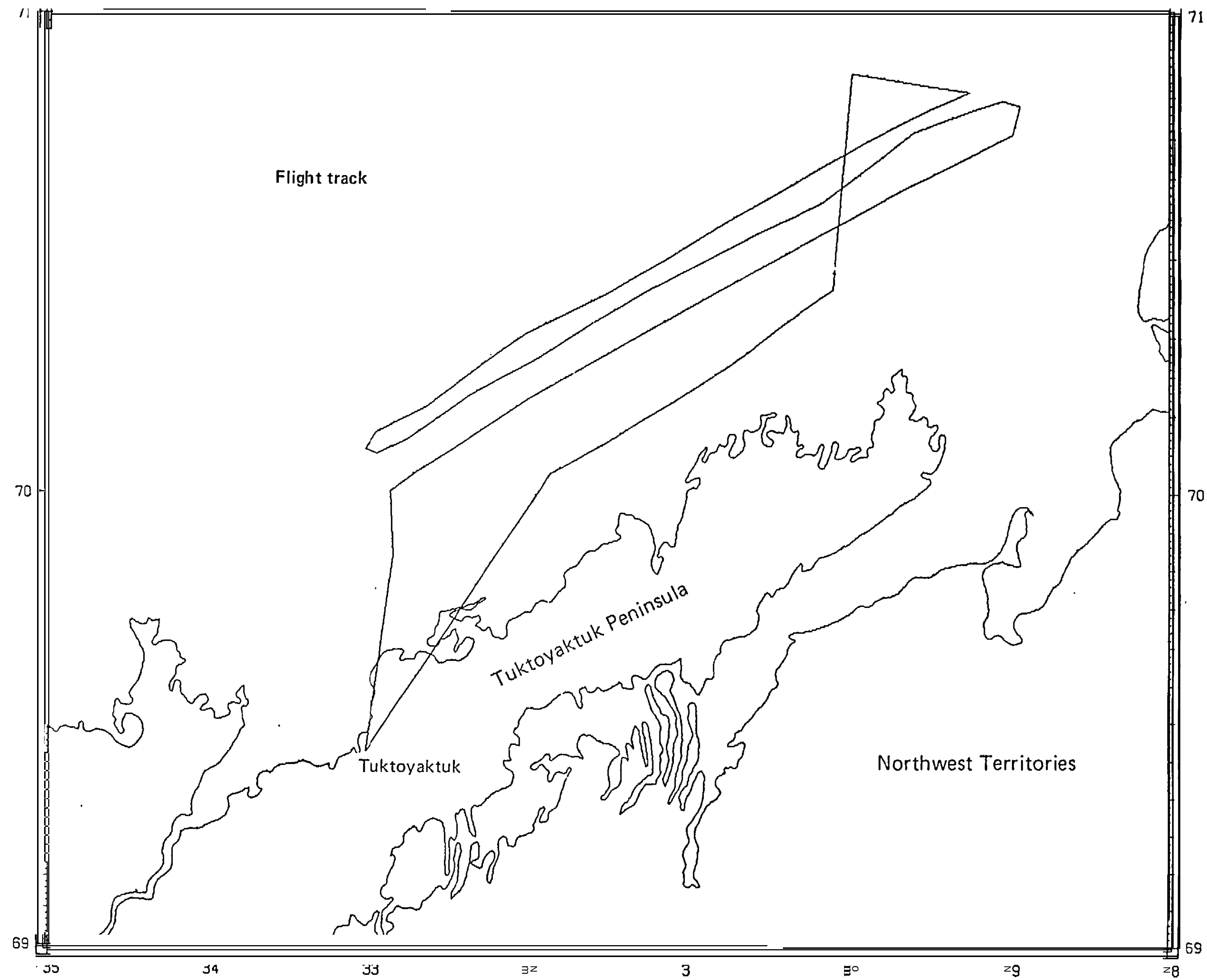
Flight track
Tuktoyaktuk Peninsula
Tuktoyaktuk
Northwest Territories
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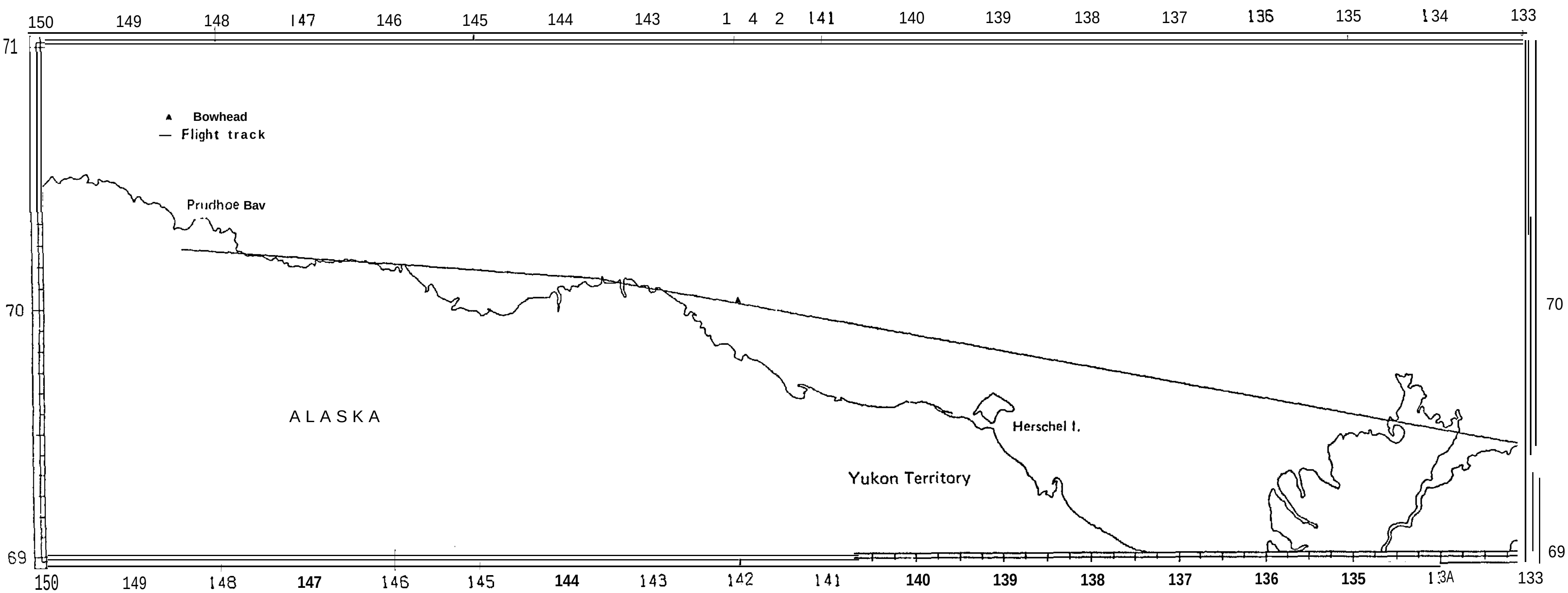
Fig. 25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69
Bowhead
Flight track
Prudhoe Bay
ALASKA
Herschel I.
Yukon Territory

Fig. 26